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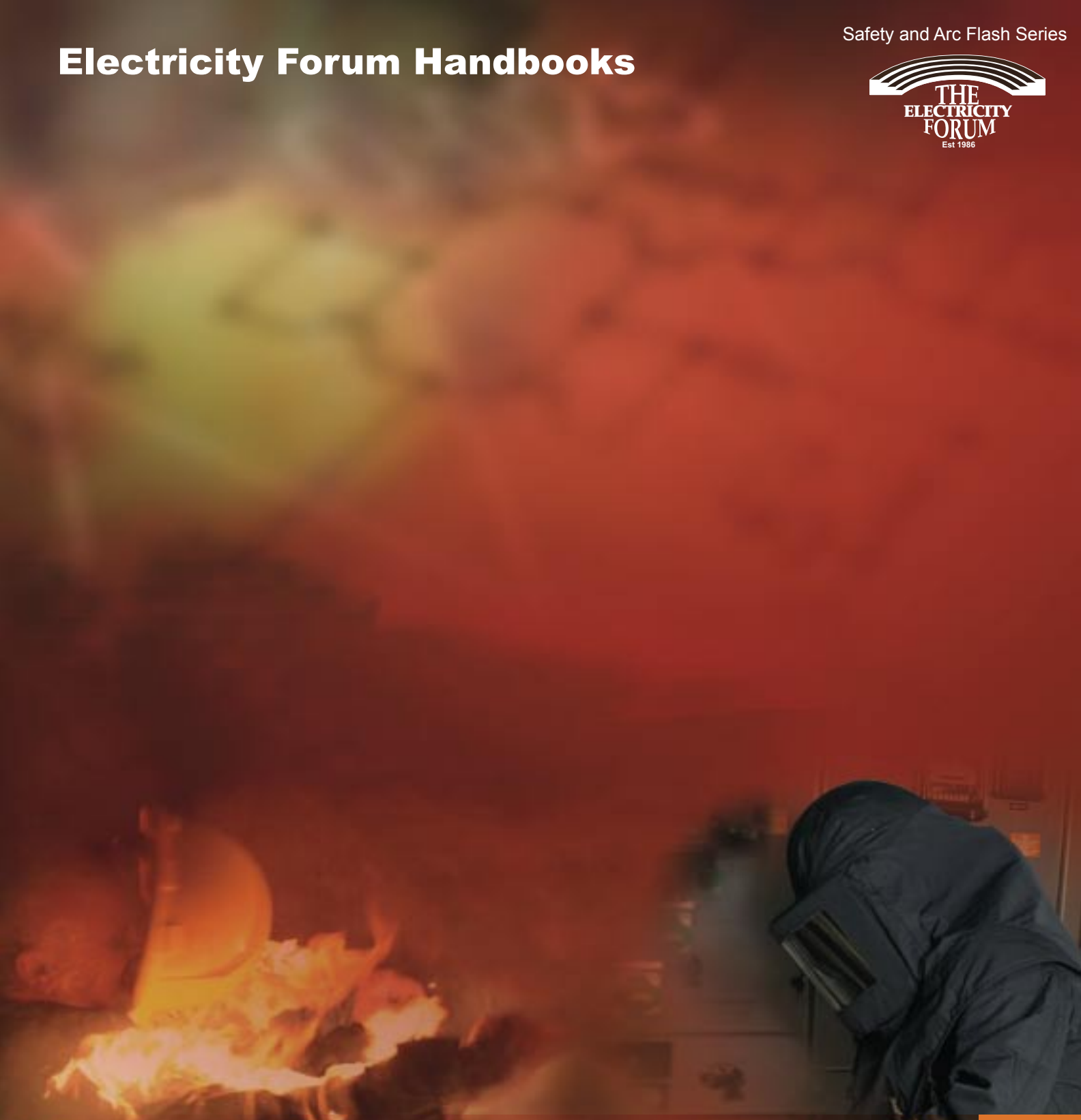

ELECTRICAL SAFETY AND ARC FLASH Handbook

Volume 7

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ELECTRICAL SAFETY AND ARC FLASH Handbook

Volume 7

Published by The Electricity Forum

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ELECTRICAL SAFETY AND ARC FLASH Handbook

Volume 7

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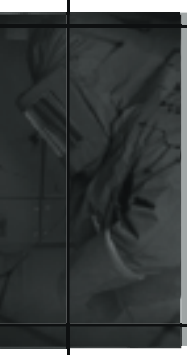
ISBN-978-1-897474-24-2
The Electricity Forum
215 - 1885 Clements Road,
Pickering, ON L1W 3V4

Printed in Canada



Introduction

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Table of Contents

FORWARD
By Jim Neumann, Vice President, EDSA Micro Corporation U.S. Department of Energy 4

ESTABLISHING AN ARC FLASH LOSS PREVENTION PROGRAM
By John F. Welch, Jr., Marvin O. Tibbetts, III, Apostolos Vranis, P. E and Robert E. Hoyt, PhD. M.C. Dean, Inc. 7

ARC FLASH: DO YOU UNDERSTAND THE DANGERS?
By John C. Pfeiffer, P.E., President, Pfeiffer Engineering Co Administration, U.S. Department of Energy 18

CREATING A LOCKOUT/TAGOUT PROGRAM
Excerpts from Oklahoma State University Program for Control of Hazardous Energy 29

10 STEPS OF AN EFFECTIVE ARC FLASH HAZARD SAFETY PROGRAM
By EasyPower, ESA Inc. 32

ELECTRICAL SAFETY HAZARDS
By Ken Cybart, Littelfuse 35

ARC FLASH BASICS: TESTING UPDATE
By M. Lang and T. Neal, Ferraz Shawmut 70

TRANSMISSION AND DISTRIBUTION SAFETY
Occupational Safety & Health Administration (OSHA) 77

ARC FLASH SAFETY SOLUTIONS
Courtesy of Eaton 83

EFFECT OF INSULATING BARRIERS IN ARC FLASH TESTING
By Robert Wilkins, Mike Lang, and Malcolm Allison, IEEE 85

SIMPLIFIED ARC FLASH HAZARD ANALYSIS USING ENERGY BOUNDARY CURVES
By Antony C. Parsons, W. Blane Leuschner, and Kevin X. Jiang, members, IEEE Department of Energy 92

LOW-VOLTAGE CURRENT-LIMITING FUSES CAN REDUCE ARC FLASH ENERGY
By Richard L. Doughty, Thomas E. Neal, Terry L. Macalady, Vincent Saporita, Kenneth Borgwald Administration (OSHA), Cooper Bussmann and IEEE 99

SIGNIFICANCE OF SCENARIOS IN ARC FLASH STUDIES
By Brian Radibratovic, PhD, Director of Power Engineering, EDSA 109

FORWARD ARC FLASH: NOW YOU SEE IT...

By Jim Neumann, Vice President, EDSA Micro Corporation U.S. Department of Energy

ARC FLASH HAS OFFICIALLY BECOME UBIQUITOUS.

It's been Facebooked, Twittered, You-Tubed, Linked-in, and Wikipedia'd. And yet – despite its global name recognition – a worker is killed every 28 hours by an electrical accident in the workplace. According to an IEEE study involving more than 120,000 workers, in more than 75 percent of those accidents, arc flash is the culprit.

Electrical accidents represent a statistically small percentage of all work-related incidents – often occurring even in facilities that have passed formal inspections within recent months – but they are disproportionately fatal. In a seven-year study conducted by the U.S. Department of Labor's Bureau of Labor Statistics, 2,576 U.S. workers died and another 32,807 sustained lost-time injuries, losing an average of 13 days away from work, due to electrical shock or burn injuries.

The Internet is brimming with information about arc flash: 364,000 hits on Google, 11.2 million hits on usa.gov, and even 445 chilling videos on YouTube. So why are U.S. workers still getting killed on an almost-daily basis?

ARC FLASH: THE ELEMENT OF SURPRISE

The problem is that an arc flash incident can occur nearly anywhere, without warning, anywhere high voltage is used. Incidents can even occur in facilities that have been rigorously inspected, like data centers, manufacturing plants, commercial buildings, convention and hospitality centers, power generation and distribution infrastructure, retail space, or other facilities where high levels of electrical power are needed.

But just as law enforcement officials can only attempt to preempt attacks by terrorists – by increasing surveillance, training those on the front lines on what to look for, investing in protective infrastructure, and so on – facility operators have not historically been able overcome the core problem: predicting when and where incidents will occur.

There are half-dozen basic obstacles that, until very recently, have kept organizations from being able to accurately determine the potential for arc flash exposure within their facilities, and educate workers about threats within their work environments:

1. Now you see it, now you don't: In a typical facility, day-to-day operating conditions are too dynamic to allow for the accurate prediction of arc flash threats. People joke about trying to service an aircraft's engines while it's still in flight, but eventually an aircraft lands. In a mission-critical facility, there's never a risk-free time to conduct service, maintenance, or technology upgrade procedures. Because these procedures have to be done on "live" equipment, errors become more likely.

2. While you were reading this, the threat escalated: The gradual aging and deterioration of power cabling, connectors, and other components create a corresponding increase in the potential for arc flash threats. Unfortunately, the rate at which this deterioration can cause arc flash problems is completely unrelated to the timetable that arc flash studies are scheduled to be conducted (just as few people arrange to have their heart attacks during the same 30-minute window that they are in their physician's office for an annual check-up).

3. Need to have vs. Nice to have: NFPA 70E Article 130.3 requires that an arc flash study be conducted at least every five years or whenever a major modification occurs. These studies are typi-

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WARNING
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3.77 Cal/cm^2 Flash Hazard at
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cally very complex and usually require that an outside expert be retained. They are also very costly, increasing in cost with the size of the facility for data collection; revision of one line drawings; short circuit and protective device coordination studies; warning label installation; and arc flash training. For all of their good intentions, companies can be slower to spend money on things like inspections until the need for them is plainly evident.

4. It's an arduous undertaking that never really ends: Greek mythology speaks of a man named Sisyphus who angered the gods and was given the punishment of spending eternity rolling a boulder to the top of a tall peak, only to have it roll down the other side of the peak each time. Though that's a little more grueling than conducting an arc flash study, there are similarities: an arc flash study is a painstaking, labor-intensive undertaking, and one that is outdated almost as soon as it is completed, due to equipment changes, components being handled during maintenance procedures, or just plain aging.

5. A false sense of security: In a freshly inspected facility, workers assume that arc flash safety levels are at their highest, which can lull them into believing that it is safe to lower their guard in terms of safety precautions. This is particularly true in facilities that are "self-inspected". Self-conducted inspections seldom do the thorough job of experienced experts, setting the stage for potentially catastrophic problems down the road.

6. NIMBY becomes NIMMCF (Not in my Mission Critical Facility): When many people hear a dangerous term like "arc flash", some have a difficult time envisioning that their air-conditioned data center or pristine mission-

Prior to entering an energized area and beginning work, site personnel simply query the system for a real-time arc flash status..

critical facility poses a safety threat to workers. But the threat of arc flash is present anywhere there are high levels of electrical power: workers have been injured and killed using ladders, power-washing equipment and even a frightening story in the medical publication, Anesthesia & Analgesia, there is description of a nurse electrocuted in an operating room that was fully compliant with current National Fire Protection Association (NFPA) electrical codes.

A NEXT-GENERATION ASSESSMENT

But within the past 18 months, a new software technology called "power analytics" has emerged that – though created primarily to ensure power reliability and energy efficiency – has also been proven to provide real-time arc flash assessments.

The term, power analytics, refers to integrated software technologies that help organizations to ensure that their electrical power infrastructure is optimally designed (at the CAD stage), performs precisely as intended in terms of reliability and energy efficiency (once in the deployment/diagnostics stage), and operates flawlessly as organizations make real-time transitions between public and on-premise power sources in the grid management stages.

Once in the deployment/diagnostics stage, the diagnostics software maintains an uninterrupted watch over site operations – continually checking all components, equipment, and systems and comparing their "real world" status back to the original CAD model. When deviations are detected, the system performs the calculations necessary to make intelligent recommendations about where arc flash hazards have the potential to emerge, and gauge their severity.

Prior to entering an energized area and beginning work, site personnel simply query the system for a real-time arc flash status. It then responds with an up-to-date recommendation on the appropriate safety procedures and PPE necessary to work in the vicinity. Recommendations are based upon IEEE 1584 and the NFPA 70E standards entitled, "IEEE Guide for Performing Arc flash Hazard Calculations", and "Standard for Electrical Safety Requirements for Employee Workplaces", respectively.

For example, when performing repairs to equipment in which a worker could accidentally be exposed to an electrical hazard, power analytics systems will provide specific guidance on gloves, clothing, goggles, helmet, etc., that the worker should wear to increase his or her safety in the event of an accident. Forewarned about the nature of the threat, workers will be able to proceed with a higher degree of knowledge about specific safety risks they may encounter.

There are no crystal balls out there that are 100 percent foolproof when it comes to detecting arc flash hazards. But the new generation of power analytics technologies is the most promising development yet in ensuring that workers are forewarned to the greatest extent possible about how to protect themselves from this all too-common threat.

Establishing an Arc Flash Loss Prevention Program

By John F. Welch, Jr., Marvin O. Tibbetts, III, Apostolos Vranis, P.E. and Robert E. Hoyt, PhD. M.C. Dean, Inc.

1. EXECUTIVE SUMMARY

The facts are eye opening. An arc flash explosion occurs between five and ten times a day somewhere in the U.S. Up to 80% of all electrical injuries are burns resulting from an arc flash and the resultant ignition of flammable clothing. Electrical accidents contribute to billions of dollars of lost property and litigation related to injuries and loss of life.

To reduce the potential for injuries or deaths from arc flash incidents, the Occupational Safety and Health Administration (OSHA) has issued regulations designed to promote workplace safety. Concurrently, the National Fire Protection Association (NFPA) is working to "reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating consensus codes and standards, research, training, and education". Together, these two organizations are setting the industry standard for regulations and standard practices that influence workplace safety.

The industry has responded by designing safer power systems, reducing worker exposure to arc flash energy, and initiating Arc Flash Loss Protection (AFLP) programs. This White Paper will discuss arc flash loss prevention regulations and industry best practices, the causes and effects of arc flash hazards, the need for an AFLP Program, and the steps necessary to implement an effective AFLP Program.

2. PURPOSE OF THIS WHITE PAPER

Most arc flash guidance materials available today are written by the engineering community for the engineering community. Yet, it is the middle and upper managers, many of whom do not have engineering or technical backgrounds, who are responsible for making loss prevention decisions, including those aimed at minimizing and mitigating the risk associated with electrical hazards in the workplace. Therefore, this white paper is focused on those individuals accountable for protecting their organizations from harm.

This white paper is designed to:

- Give middle and upper management an executive level description of the details surrounding arc flash and the industry's best proven business practices. After reading this paper and applying the knowledge gained to his/her organization, executives should have the confidence to begin the process of assigning the right team and resources needed to develop the methodology that best carries out a safety and arc flash loss prevention program tailored to their organizations.
- Provide the technical manager with a support document that can be presented to upper management along with his/her recommended initiatives to improve corporate safety policies by integrating an Arc Flash Loss Prevention (AFLP) Program.
- Provide business leaders a quick reference guide to the questions they may have involving who is responsible (in the eyes of OSHA and the judicial system), how to resource, how to control cost and how to build a sustainable program that can be monitored by a non-technical manager.
- Equip risk managers with a methodology to process a loss prevention program targeted to exposure related to arc flash. This includes the means to identify, evaluate, choose, implement, monitor and manage a comprehensive program that is sustainable and provides measureable data that can be used to calcu-

late best risk management decisions.

• Caution on the use of "over-simplified" allowable tables and charts the industry has developed to establish arc flash protective measures. The risks include controlling the cost of expensive personal protective equipment (PPE) that may or may not be needed and giving untrained workers the false sense of confidence when working on energized electrical equipment. The result is a mismanaged safety program.

3. GENERAL INFORMATION

To better understand the need to protect electrical workers from electric hazards, such as shock, arc flash, and arc blast hazards, one must first understand the impact of an arc flash. The following section defines arc flash, lists causes, and details the possible results of an arc flash incident.

3.1 WHAT IS AN ARC FLASH?

An arc flash is a hazardous arcing short circuit or fault, potentially occurring anywhere in an electrical system, phase-to-phase or phase-to-ground. The arcing fault causes rapidly excessive heating of air molecules, ionizes and vaporizes conductive metal materials and generates a densely concentrated blast of pressure formed by light and heat energy.

The arc flash blast can propel molten metal, shrapnel, and tools through the air, potentially knocking workers off of ladders and even launching them across a room.

3.2 WHAT CAUSES AN ARC FLASH?

There can be numerous causes for an arc flash incident. The most common are human error, neglecting proper preventive maintenance, and an improperly designed electrical system or legacy equipment. The following details each of the above causes:

• Human Error: An arc flash incident could occur due to human error as a result of unsafe work procedures. Most commonly, these mistakes are made during maintenance activities and are caused by mishandling a tool, wire, metal cover, etc.

• Neglecting Proper Preventive Maintenance: An arc flash incident could occur due to neglecting preventive maintenance tasks and activities. Proper preventive maintenance should include:

° Checking for loose wiring and improperly torqued electrical terminations;

° Cleaning and inspecting electrical equipment to prevent the build-up of dust, dirt, particles, debris or corrosion that could become an arc conductor between live parts;

° Periodically testing and operating the electrical equipment's moving parts that are designed to clear electrical faults;

° Adhering to NFPA 70-B Annex I defined maintenance intervals.

° Improperly Designed Electrical System or Legacy Equipment: An arc flash incident could occur due to an improperly designed electrical system, incorrect electrical system modifications and legacy electrical equipment.

3.3 WHAT ARE THE RESULTING INJURIES FROM AN ARC FLASH?

Between five and ten times a day an arc flash explosion occurs in the United States, according to CapSchell, Inc., a Chicago research company that specializes in workplace accident prevention.

Injuries resulting from an arc flash are typical of an explosion and may include flash burns, hearing loss, vision loss, general trauma and death.

Proper personal protective equipment (PPE) is critical to mitigating injuries. An arc flash incident has the ability to melt man-made fibers to one's skin. This includes underwear and bras worn under Flame Resistant (FR) clothing. Even FR clothing has an ignition point. Only clothing tested to meet specific calorie ratings can be trusted to withstand arc flash incident energies per their ratings.

Electrical dangers, including arc flashes, will always be present on the job, but proper installations, training, and safety strategies, processes and procedures for operating and maintaining electrical systems and equipment can minimize the likelihood of injuries and fatalities.

3.4 WHAT ARE THE RESULTING BUSINESS CONSEQUENCES OF AN ARC FLASH?

Arc flash incidents have numerous consequences beyond the obvious, and most serious, which are injury or death of an employee. Additional consequences include:

- Damage to Equipment
- Business Disruption
- Increased Experience Modification Rate (EMR)
- OSHA Citations
- Litigation
- Bad Public Relations

3.5 WHO ARE THE AUTHORITIES?

Effective August 31, 2007, the Occupational Safety and Health Administration (OSHA) has provided legal motivation to employers to protect from arc flash hazards any personnel who install or maintain electrical systems. The agency published a final ruling in the Federal Register on February 14, 2007 that mandated new guidelines for equipment design, equipment classification, electrical system installation and electrical maintenance practices.

The mission for OSHA, part of the Department of Human and Health Services, is "to assure the safety and health of America's workers by setting and enforcing standards; providing training, outreach, and education; establishing partnerships; and encouraging continual improvement in workplace safety and health". This makes OSHA the nation's preeminent enforcer of workplace safety regulations.

The National Fire Protection Association (NFPA), established in 1896, serves as the world's leading advocate of fire prevention and is an authoritative source on public safety. In fact, the NFPA's 300 codes and standards influence every building, process, service, design, and installation in the United States, as well as many of those used in other countries. The NFPA publishes both the NFPA 70 National Electrical Code (NEC) and the Standard for Electrical Safety in the Workplaces (NFPA 70E). These publications are nationally recognized as providing the industry's acceptable standard practices used by fed-

eral, state and local building authorities to regulate safe electrical installation and maintenance. The NFPA's purpose is to "reduce the worldwide burden of fire and other hazards on the quality of life by providing and advocating consensus codes and standards, research, training, and education".

The NFPA routinely updates their publications which allow local and state building authorities to adopt these changes into their laws and ordinances.

OSHA's previous update to its general-industry electrical standard was in 1981 and its renewed effort in 2007 adds multi-agency consistency, as it aligns itself more closely with the 2000 edition of the NFPA 70E-2000 and the 2002 edition of the NEC-2002.

The American Society of Safety Engineers (ASSE) represents 30,000 safety, health and environmental professionals committed to safety in the workplace. In a letter to OSHA in 2004, ASSE's president wrote, "It is appropriate to move forward with this revision, given the seriousness of electrical hazards and the fact that nearly 300 workers are killed each year from contact with electrical current or as the result of injuries caused by fires and explosions related to electrical accidents."

Guidelines recently published by the Institute of Electrical and Electronics Engineers (IEEE), has developed "IEEE Standard 1584, Guide for Performing Arc Flash Hazardous Calculations." The purpose of IEEE 1584 is to:

"Provide techniques for designers and facility operators to apply in determining the arc flash hazard distance and the incident energy to which employees could be exposed during their work on or near electrical equipment".

The IEEE guide provides the means of identifying and quantifying potential arc flash hazards so that proper labeling and personal protective equipment (PPE) can be selected.

The American National Standards Institute (ANSI) is a non-profit organization that is the voice of U.S. standards and conformity assessment system. Its members are required to be accredited. The ANSI mission is to:

"Enhance both the global competitiveness of U.S. business and the U.S. quality of life by promoting and facilitating voluntary consensus standards and conformity assessment systems, and safeguarding their integrity."

The NFPA and IEEE are both members of ANSI.11

The National Institute for Occupational Safety and Health (NIOSH) is the federal agency responsible for conducting research and making recommendations for the prevention of work-related injury and illness. NIOSH is part of the Centers for Disease Control (CDC) in the Department of Health and Human Services (DHHS). NIOSH includes research and development for the Mine Safety and Health Administration (MSHA). A separate agency from OSHA, MSHA, part of DHHS, is the safety and health inspection and enforcement agency for the nation's mines including coal, gravel, sand, stone, and metal among others.

In 2007, NIOSH recognized arc flash as the most common cause of electrical industry in the mining workplace. Also in 2007, NIOSH published "Understanding and Quantifying Arc Flash Hazards in the Mining Industry". In this paper, NIOSH states:

"Arc flash hazards are an issue that has not yet been effectively addressed in the mining industry, but intervention strategies and techniques developed in other industries over the last two decades can be applied to help solve this problem. NFPA 70E, Standard for Electrical Safety in the Workplace, is the most comprehensive and widely used source for recommendations on this topic".

4. WHO IS RESPONSIBLE?

In OSHA's General Duty Clause and the Multiple-Employer Citation Policy Section 5(a)(1) of the Occupational Safety and Health Act, employers are required to furnish their employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm to the employees.
In addition to the employers who directly employ the exposed electrical workers, building owners, property managers, facility managers and general contractors have responsibility to the process as well. In response to the Associated Building Contractors' concerns on this subject, OSHA posted on its website these definitions of the four employer role categories:

- Exposing: This is an employer whose own employees are exposed to the hazard.
- Creating: This is an employer who creates a hazard to which a different employer's employees are exposed.
- Correcting: This is an employer who has been brought in to specifically correct a hazard.
- Controlling: This is an employer with general supervisory authority over the worksite with the authority to have safety and health violations corrected.

5. "THOU SHALL" – SAYS WHO?

As stated earlier, OSHA regulations, effective August 31, 2007, mandate that employers shall protect employees from electrical hazards. OSHA is clearly the lead enforcer, and is supported by both the NFPA 70E-2004 and NEC-2005.

OSHA'S STANDARDS AND ENFORCEMENT POLICIES

In the United States, the Office of the Federal Register (OFR) is the official archive of laws published by Congress, presidential documents, descriptions of federal agencies and the regulations by which they govern.

OSHA's mission, as pointed out previously is to assure the safety and health of U.S. workers. The agency's governance includes both setting and enforcing standards.

OSHA recorded its new electrical safety standards in the Federal Register on February 14, 2007 (Department of Labor, OSHA, 29-CFR, Part 1910, Electrical Standard, Final Rule). These standards became enforceable on August 31, 2007.
In this government archive, OSHA states: "The Occupational Safety and Health Administration (OSHA) is revising the general industry electrical installation standard found in Subpart S of 29 CFR Part

1910. The Agency has determined that electrical hazards in the workplace pose a significant risk of injury or death to employees, and that the requirements in the revised standard, which draw heavily from the 2000 edition of the National Fire Protection Association's (NFPA) Electrical Safety Requirements for Employee Workplaces (NFPA 70E), and the 2002 edition of the National Electrical Code (NEC), are reasonably necessary to provide protection from these hazards. This final rule focuses on safety in the design and installation of electric equipment in the workplace. This revision will provide the first update of the installation requirements in the general industry electrical installation standard since 1981. OSHA is also replacing the reference to the 1971 NEC in the mandatory appendix to the general industry powered platform standard found in Subpart F of 29 CFR Part 1910 with a reference to OSHA's electrical installation standard."

(To view the latest NFPA and NEC regulations, visit the NFPA website, http://www.nfpa70nationalelectricalcode.com.)

OSHA regulations state in 1910.333 (a) that workers should not work on live equipment (greater than 50 volts) except for one of two reasons:

• If de-energizing introduces additional or increased hazards such as the shutdown of ventilation to a hazardous location, interruption of life support equipment, or deactivation of emergency alarm systems.

• If it is infeasible due to equipment design or operational limitations such as when voltage testing is required for diagnostics.

When it is necessary to work on energized equipment, workers should follow safe work practices including assessing the risks, wearing proper PPE, and using the proper tools.

6. PUBLISHED COMPLIANCE & STANDARDS GUIDELINES

The NFPA led diligently with IEEE to gather a true consensus among other agencies, industry associations and industry organizations to create with accreditation from ANSI compliance standards and guidelines to improve and mitigate hazards in the workplace surrounding arc flash.

The NFPA's current industry standards publications referencing arc flash protection practices include:

• How to Warn and Label: NEC-2002; and

• How to Implement Work Practices: NFPA 70E-2004.

(For a complete understanding and a review of the NFPA 70E, visit the NFPA web site at http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=70E.)

The following subsections of that code detail the scope of information provided by the NFPA:

6.1 WARNING & LABELING: NEC-2002

NEC-2002, 2005, 2008 Article 110.16, covering the provision for flash protection, states that electrical equipment "likely to require examination, adjustment, servicing, or maintenance while energized shall be field marked to warn qualified persons of potential electric arc flash hazards." It makes reference in FPN No.1 to NFPA 70E-2000 that provides the associated work practices and is described below. The article makes reference in FPN No. 2 to the ANSI Z535.4-1998 specification that provides the industry's recognized standard for product safety signs and warning labels.

Note: Even though OSHA references NEC-2002 in its revisions to Subpart S of 29 CFR Part 1910, the governing regulations were developed specifically to minimize the need for revision as new standards to the NEC are released. Therefore, to date, NEC 2008 is the recommended standard to follow.

6.2 IMPLEMENTING THE WORK PRACTICES: NFPA 70E-2004

This standard provides guidance on implementing appropriate work practices required to safeguard workers from injury while working on or near exposed electrical conductors or circuit parts that could become energized. Some requirements of NFPA 70E-2004 include:

• Equipment must be placed in a safe working condition;

• Personal Protective Equipment (PPE) must be worn when work is conducted within a flash protection boundary. This work includes lockout/tagout, testing, and inspecting visual breaks within flash boundaries of energized equipment; and

• Facility owners are required to perform a flash hazard analysis prior to allowing a worker to work on energized equipment. This is necessary for determining the flash protection boundary and type of PPE required.

Note: Even though OSHA references NFPA 70E-2000 in its revisions to Subpart S of 29 CFR Part 1910, the governing regulations were developed specifically to minimize the need for revision as new standards from the NFPA are released. Therefore, to date, the NFPA 70E-2004 is the current consensus standard to follow in the industry.

7. CAUTION: USING SIMPLIFIED TABLES & IEEE STANDARD 1584 CHARTS

It is best practice and is always recommended that workers follow de-energized lockout/tagout safety procedures while working on electrical equipment. However, when workers must work on energized electrical equipment, they must be qualified to do so, be made aware of the hazards and follow proper work practices as described in NFPA 70E. This includes wearing proper personal protective equipment (PPE).

This section addresses the concern with using the published tables. These charts allow for simplified analysis techniques to determine the required arc flash PPE based on IEEE Standard 1584.
IEEE states that:

"While the method does not exactly calculate incident energy levels and flash protection boundaries at the buses under consideration, it does allow for an accurate determination of required PPE levels and maximum flash-protection boundary distances."

Using this technique could create the environment for the following:

• Restrictive Safety Equipment: For

example, Category 4 PPE is a full suit with hood that is restrictive. Working in a Category 4 suit is very slow, time consuming, and air flow restrictive. A Category 4 suit also limits the field of vision and does not allow reasonable dexterity on complex work. Having to default to maximum flash-protection boundaries could make the use of the required PPE unreasonable and increase the likelihood of human error.

• Mismanaged Safety Program: The same discipline that seeks simplicity may roll into expensive purchase orders for PPE, improper inventory control, improper use, and documentation control; i.e. permitting for energized work.

• False Sense of Security: Any part of the safety program can put untrained workers and others at risk by misinterpreting the PPE as "maximum protection" when, in this instance, lockout/tagout procedures would provide the adequate protection.

It is important to understand the organizations' real electrical arc flash hazards and to create a culture that focuses on the true seriousness of an arc flash. Misapplication creates unforeseen hazards that can lead to loss and elevated costs.

8. HERE IS HOW – AN ARC FLASH LOSS PREVENTION (AFLP) PROGRAM

OSHA has provided the legal motivation for an AFLP program by setting and enforcing new arc flash protection regulations. Additionally, the NFPA established some reference guidelines and recommendations to identify and implement an arc flash protection strategy/program. Finally, the electrical engineering community has developed recommended products and professional services to implement arc flash protection. Unfortunately, too often due to poor execution and application of these services and products, an organization is exposed to the risk of an incident, OSHA fines, and damaged reputation.

8.1 RISK MANAGEMENT APPLIED

A serious gap exists in most arc flash programs today. These programs are not sustainable unless there is a process that assures:

- Complete List of Electrical Assets
- Risk Assessment
- Hazards are Identified & Labeled
- Established Processes
- Trained Personnel
- Document Control
- Management Controls
- Reviewed & Updated

This section 8.0 specifically addresses the necessary steps to build a sustainable Arc Flash Loss Prevention (AFLP) Program and gives information that risk managers and others can use. Some major areas commonly missed include:

• Identifying: Discovering the complete electrical system, including the intent of the engineered design, system changes, and any unforeseen electrical arc flash hazards that may exist in the electrical system.

• Evaluating: Assessing the potential frequency and severity of risk associated with each electrical system asset discovered by performing a site specific engineered arc flash analysis, documenting each electrical asset to its level of risk and labeling it accordingly in the field.

• Quantifying: Equipping risk management with the ability to quantify the number of electrical assets by severity and the frequency by which personnel are exposed to the risk of arc flash. With this information, risk management can decide the emphasis to place on loss control measures to avoid, retain and/or insure the risk associated with arc flash.

• Developing & Controlling Process: Assuring that OSHA's and NFPA's regulations and recommended work practices are properly integrated to the organization's work flow processes. This includes work ticket initiation, work practices in the field, field documentation, work history logging and safety program enforcement.

• Training: Assuring that program consistency is accomplished with an ongoing training program that is integrated into the corporate safety program process. This includes initial employee training, new employee orientation, employee scheduled refresher training, outside contractor/vendor compliance training and AFLP program updates.

• Protecting: Establishing a program to identify proper types and inventory of Personal Protection (PPE) is readily available for use, is properly being applied, and is routinely inspected to assure it's protective reliability.

• Controlling Cost: Developing a measured approach to spending money on expensive PPE. Haphazardly buying equipment just for show is expensive and creates hazards in itself by giving a false sense of security, putting workers in harms way when they don't even realize it.

• Documenting: Assuring that the organization is ready for an OSHA audit that could occur unannounced without an incident or as a follow-up behind one. OSHA is pretty straightforward: "If it's not documented, it didn't happen." An AFLP Program assures the documentation process properly occurs to show training, work processes, engineering updates and electrical asset identification updates.

• Reviewing & Updating: Any sustainable process has a method to track, evaluate and improve. A sustainable AFLP is no different and should place the controls in the hands of management.

An Arc Flash Loss Prevention (AFLP) Program goes beyond an Arc Flash Analysis and Arc Flash Study. A site-specific engineered analysis and study are critical pieces. However, an AFLP Program is a commitment to safety for zero accidents by a comprehensive process that assures sustainability by incorporating discovery, engineering, identification, reporting, administrative planning, training, field execution, documentation control, program review, and annual program updates. These are the elements that answer the question: "What happens when…?"

8.2 ARC FLASH LOSS PREVENTION (AFLP) PROGRAM

An effective AFLP Program is not something that can be created and then ignored. The true value of an AFLP Program can only be determined after it has been implemented and the long term reduction in arc flash incidents document-

ed. This requires a program that continually evolves as equipment and technology evolve and as personnel come into and out of the program. To accomplish this, the program must be viewed as cyclical with each step in the lifecycle of the program. New information must be incorporated to ensure the safety of the workers is paramount and uncompromised. Figure 1, presented in the Appendix, illustrates the AFLP Program lifecycle and highlights the interdependency of each of six steps involved in the process. These six steps are described in detailed below.

8.2.1 DISCOVERY & ENGINEERING

AFLP Program discovery initially involves gathering pre-existing engineering data. For a new construction project, the data is pulled from the design and construction drawings. Existing facilities will require site visits to verify the engineering data and drawings (to the extent that such exist). AFLP Program discovery also includes interviews, historical failures and fault data collection, and data gathering on the facilities' department operating process associated with issuing and maintaining records that involve work tickets/purchase orders for electrical maintenance activities.

AFLP Program engineering and analysis derived from the discovery details will result in updated risk assessments, recommended system improvements (risk/reward notes), engineered and design improve coordination studies, and updated electrical diagrams.

8.2.2 IDENTIFICATION & DOCUMENTATION

Each electrical asset must be labeled and identified with a warning label that meets the ANSI Z535.4-1998 specification per the reference in NEC-2002 or later revision.

AFLP Program submittals should include accumulated data used for risk assessments, electrical asset inventory list, arc flash category results, engineered drawings, TCC curves, breakers and fuses, set points, and copies of labels.

8.2.3 Program Preparation & Administration

Key elements of program administration include:

- Listing staff responsibilities and documenting the AFLP Program process for internal coordination;
- Creating the AFLP Program document designed for electrical asset control;
- Initiating Personal Protective Equipment (PPE) selection. PPE inventory levels should be based on the probability of use, AFLP Program category classification, number of personnel, size, voltage classes, boundary levels; and
- Initiating the AFLP Program Standard Operational Procedure manual submission tailored to the specific facility. This manual shall be updated annually and cataloged accordingly.

8.2.4 PROGRAM TRAINING & CERTIFICATION

To ensure that an AFLP Program remains in compliance, one must invest in certified AFLP Program training for its personnel. This includes:

- Providing administrative staff AFLP Program training for personnel who approve and issue work tickets, coordinate with outside contractors, and maintain activities logs.
- Providing field worker certified AFLP Program training to "qualify" personnel to work on the facility's electrical system. This includes initial startup, ongoing and new employee training, as well as the methodology used to train outside contractors.

8.2.5 FIELD EXECUTION & DOCUMENT CONTROL

Field execution and document control are essential elements of an AFLP Program. They include:

- Integrating AFLP Program methods into internal maintenance work tickets, change control and service history records.
- Integrating AFLP Program methods into external service providers such as outside contractors. These include credentialing, control of scope of work, change control, and as-built documentation.

8.2.6 PROGRAM REVIEW & UPDATE

On a quarterly or bi-annual basis, depending on the complexity and history of the program, it is important to review the previous period's experience and activities. This includes interviews with field personnel, staff and management. It also includes a review of field documentation and field inspection (visual) for accurate records, logs, and electrical system modifications that need to be labeled and classified.

On an annual basis, all the maintenance records, interviews and system modifications should be reviewed and records updated. From this activity, the newly updated annual AFLP Program Standard Operating Procedural manual shall be put into use along with updated engineering drawings and records.

An effective AFLP Program includes more than the initial electrical engineering arc flash analysis that many professional service companies are performing today. Establishing a comprehensive program that is sustainable is a much more complex undertaking. It includes creating the checks and balances that assure program continuity. The six-step AFLP Program process, which is both proven and tested, helps avoid accidents, reduces risk and provides responsible document control as proof that the program is in compliance with OSHA and the NFPA.

9. CHOOSING THE RIGHT AFLP PARTNER – SELECTION CRITERIA

Selecting an AFLP Program facilitating partner is an important step in creating an AFLP Program. Critical evaluation factors include:

- Engineering capabilities,
- Employment of certified safety officers,
- Experience and specific industry expert is,
- Software capabilities, and
- Customer service and support.

An AFLP Program facilitating partner should be credentialed in programs similar to the program that is best suited to

the facility. Important factors to consider include:

• Selecting an electrical engineering firm that is trustworthy, developed specific industry expertise and has experience in the specific type of operation, facility and safety requirements needed.

• Asking the AFLP Program firm for the resumes of individuals who will work on the project. This should include engineers, electricians and safety officers.

• Asking for a discovery safety plan and making sure the partnering firm is trained in NFPA 70E.

• Obtaining sample deliverables that include engineering calculations and reports, warning labels, operating procedures, etc.

• Ensuring that the firm has engineers, electricians and safety officers on staff. One should avoid firms that subcontract some of their services. This outsourcing may show either inexperience in specific areas or inability to properly resource.

• Asking the AFLP Program firm for references for similar jobs (scope, complexity, etc.).

• Asking the AFLP Program firm partner to guarantee its reporting and submissions will be reviewed and signed by a professional engineer (P.E.).

The leading engineering organizations will use arc flash analysis software to perform their arc flash studies. Some software is not electrical system-wide verified and validated for arc flash application and of limited value because it is specialized for specific equipment manufacturers. The real value of the software is an electrical system-wide verified and validated program, which adheres to NFPA and IEEE pertinent standards, and is supported by the equipment inventory technical library used for short circuit, load flow and coordination studies.

Engineering accuracy, efficiency, being able to perform the proper analytics and providing the information needed to make solid electrical system recommendations are critical. It takes an unbiased technical catalog to do so. When reviewing arc flash analysis software, it is critical to understand the software's limitations. It is also critical that the AFLP partnering firm understands:

• OSHA's newest requirements in 29 CFR Part 1910 Subpart S,

• NFPA 70E-2004 standards,

• IEEE 1584, and

• NEC-2008 standards.

A professional AFLP Program firm must be able to create engineering records and one-line electrical diagrams with incident energy levels and arc flash boundaries.

9.1 TRAINING AND PROGRAM REVIEWS BY CERTIFIED SAFETY OFFICERS

An AFLP Program firm must have a professional safety program which supports the commitment to safety for zero accidents. The AFLP Program firm shall produce resumes that show the proposed safety professionals who will work on the program have the proper credentials and a demonstrated commitment to safety for zero accidents. Those credentials should come from two of the nation's top safety credentialing organizations: the Board of Certified Safety Professionals (BCSP) and the American Society of Safety Engineers (ASSE).

The AFLP Program firm's safety officers shall have the knowledge and experience to train personnel on NFPA 70E, lockout/tagout, OSHA penalties, the limitations of "unqualified" workers, identifying energized components, and determining equipment voltage classes.

9.2 CUSTOMER SERVICE AND SUPPORT

The AFLP Program firm shall understand the electric utility's configuration, short circuit capability and the available fault currents entering the facility. The ability to access accurate data from the electric utility is critical to ensuring all of the calculations fundamentally align.

The AFLP Program provider must be experienced and have the capability to create recommendations and options to mitigate and lower the risks associated with arc flash for both the proposed (new) or existing installation. These recommendations, as stated in the Potential Mitigation Techniques Overview in the Appendix, may include changes to the types of overcurrent protection, selectivity of settings for different settings between operation and maintenance, corrective adjustments and other recommendations that could reduce or eliminate arc flash hazards. (An additional benefit of reducing or eliminating hazards is to downsize the arc flash category, which reduces the PPE cal/cm2 requirements.) Any recommendations made by the AFLP Program provider shall include a scope and budget.

10. CONCLUSION

Electrical dangers, including arc flash will always be present on the job, but with proper designs, installations, processes, procedures, training, and safety strategies/programs, the likelihood of arc flash can be minimized and thus injuries and fatalities can be prevented. The cornerstone of any strategy to reduce arc flash hazards is a properly defined, implemented and administrated Arc Flash Loss Protection Program.

11. DEFINITION OF TERMS

Certain words and phrases are specific to any discussion of arc flash hazards and are, therefore, vital to understanding the OSHA and NFPA regulations and guidelines.

ARC FLASH BOUNDARIES

The three classifications of arc flash boundaries are 1) Limited Approach, 2) Restricted Approach, and 3) Prohibited Approach. These boundaries are distances determined from the potential origination source of the arcing fault which produces 1.2 calories/cm2 incident energy.

Figure 2, provided in the Appendix, illustrates the distance for each boundary from the potential origination point of the arc flash. Note: This is equal to holding your finger over the tip of a flame from a common household lighter for one second.

The following are descriptions of each boundary.

• Limited Approach Boundary: The boundary around exposed, live parts that may not be crossed by "unqualified"

person(s) unless accompanied by a "qualified" person(s).

• Restricted Approach Boundary: The boundary that marks the area from exposed energized "live" parts that may be crossed only by "qualified" persons using appropriate shock prevention techniques and equipment.

• Prohibited Approach Boundary: The boundary that marks the area from exposed energized "live" parts that may be crossed only by "qualified" persons using the same type of protection as if direct contact with live parts is planned.
(See Table 1 for detailed distances for Approach Boundaries to Live Parts/or Shock Protection.)

ARCING TIME

Arcing time is the amount of time that the arc flash incident has the potential to last depending on the electrical system's settings of the upstream overcurrent protective devices.

CALORIE

A calorie is a unit of measure for the amount of energy required to raise one gram of water one degree Celsius at one atmosphere. Second degree burns occur at 1.2 calories per centimeter squared per second.

DISTANCE

The distance an individual is from an arc flash originating source. In more sophisticated electrical systems, equipment manufacturers have begun using remote operating equipment, circuit breaker racking, and other means to place distance between personnel and potential arc flash sources.

FAULT CURRENT

Fault current is the abnormal flow of electrical current due to an electrical fault condition. Overcurrent devices (i.e. circuit breakers, fuses, etc.) are designed in electrical systems to protect electrical circuits from too much current flow. They work by interrupting fault currents. The method of protection is commonly known as "tripping a breaker" or "blowing a fuse". If a circuit is to be properly protected, the fault current must be high enough to operate the primary protective device within as short a time as possible. Also, the protective device must be able to withstand the fault current and extinguish internally any resulting arcs without sustaining the external arc for any significant length of time.

FLASH HAZARD

A dangerous condition associated with the release of energy caused by an electric arc.

HAZARD/RISK CATEGORY

The hazard/risk category is the danger level of the potential arc flash incident. The category ratings range from 0 to 4. Category 0 represents little or no risk and Category 4 represents the greatest risk. Table 2, provided in the Appendix, shows the types of PPE needed for each category.

Determining the actions once a hazard is identified is the key. (See Figure 3, a flow chart that outlines the evaluation procedure for Hazard/Risk Analysis.)

QUALIFIED WORKER

A qualified worker is defined as an individual who has received documented training in the hazards of working on energized equipment in general, and has been trained in the hazards of the particular equipment being serviced. Training must include the necessary information to protect him or herself from arc flash hazards including the use of proper procedures and the application of PPE.

12. FREQUENTLY ASKED QUESTIONS

When it comes to understanding the importance of an AFLP Program and how an arc flash can impact an organization, people ask a lot of questions. This section answers those most frequently asked questions.

Why Is A Flash Hazard Analysis Necessary?

First, the NFPA 70E-2004 requires facility owners to perform a flash hazard analysis prior to allowing a worker to work on energized equipment. This analysis is necessary to determine the flash protection boundaries and the type of PPE that must be worn.

How long does an Arc Flash analysis take?

It obviously depends on the size of the plant. The analysis requires inspections of all electrical bus's nameplate data, conduit type, length and feeder type (AL or CU). The typical site should take, on average, 45 minutes per bus.

What if one only wants to do an arc flash analysis?

An arc flash analysis is a good first step. An ongoing program with training, procedures, checks and balances, and documentation offers much greater risk reduction.

If an organization always subcontracts its electrical work when energized work needs to be performed, isn't the subcontractor accountable, thus no need for an Arc Hazard Study?

Yes. The subcontractor is accountable for understanding the incident energy level, and the building owner is accountable for ensuring a safe work environment. If an accident occurs, OSHA will fine the building owner and will still consider the building owner at fault.

If an employee from an outside company is injured while working on electrical equipment, is the organization that hired the outside company liable for damages?

Yes. According to OSHA, employers must ensure safe work environments for ALL who come in contact with electrical equipment.

What is an AFLP program?

AFLP stands for Arc Flash Loss Protection. An AFLP Program is a comprehensive process that assures complete program sustainability. Components include discover, engineering, identification, reporting, administrative planning, training, field execution, documentation control, program review and annual program

updates.

Why should an AFLP program be sustainable?
A true Arc Flash Loss Prevention Program must be ongoing, not just analyzing or testing equipment. An organization needs a comprehensive AFLP program PLUS one that sets up training programs for new employees, updates documentation and reports and constantly works to reduce risks and accidents.

If an arc flash occurs and an organization doesn't have an AFLP Program in place, what can happen?
Besides the risk of someone being terribly injured, burned, disfigured or even killed, an organization will also face fines from OSHA, the possibility of litigation, damaged reputation and a public relations nightmare. The risks of an arc flash are too great not to implement an AFLP Program.

Can an AFLP program be tailored specifically to an organization?
Yes. An engineering firm that is an expert in AFLP will know how to determine a facility's needs and understand processes, budgets, staff resources and infrastructure.

Will an AFLP program prevent all electrical accidents from happening?
Although the possibility of an electrical accident, including arc flashes, will always be present on the job, proper design, installation, training and safety strategies/programs can minimize the likelihood of those accidents and prevent injuries and fatalities.

What is PPE and when is it required?
PPE stands for Personal Protection Equipment used to safeguard employees who work on electrical equipment. PPE must be worn when work is conducted within flash protection boundaries, such as lockout/tagout, testing and inspecting visual breaks.

15. APPENDIX: OVERVIEWS, TABLES AND ILLUSTRATIONS

15.1 Overview – Potential Mitigation Techniques

The magnitude of the arc flash hazard depends upon several parameters, such as voltage, arcing distance or gap, short-circuit current or arcing current, grounding, and most directly by fault clearing times. The arc flash hazard zone could be viewed as that level created between isolation devices.

Therefore, the incoming section of switchgear would most likely have a higher arc flash hazard than the downstream sections of the bus on a properly coordinated system and thus the incoming sections of switchgear could require a higher level of PPE than downstream sections of the same switchgear.

The type, location, and quantity of isolation devices as well as the fault clearing times are primary parameters to lower arc flash hazards to within manageable levels. Although there are many important parameters, such as system reliability and process requirements that frequently will require significant energy and the desire to avoid a sensitive or premature trip setting, the use of the following designs represents potential mitigation techniques:

- Current limiting devices, fuses, reactors, use of multiple smaller kVA sources with increased isolation devices
- Faster arc clearing times, ground fault protection, enhanced and more sophisticated multifunctional relaying
- Multiple zone and/or selective zone relay protection
- Light sensing protective devices to detect and isolate, or even apply crowbar circuit to collapse the arc
- Use of an insulated, isolated and compartmentalized bus to prevent the spread of the arc
- Remote racking/operating devices to increase distance between arc and personnel.
- Maintenance mode switches that provide faster clearing set points with possible sacrifice in coordination during maintenance activities.

Figure 1 — Arc Flash Loss Prevention (AFLP) Lifecycle

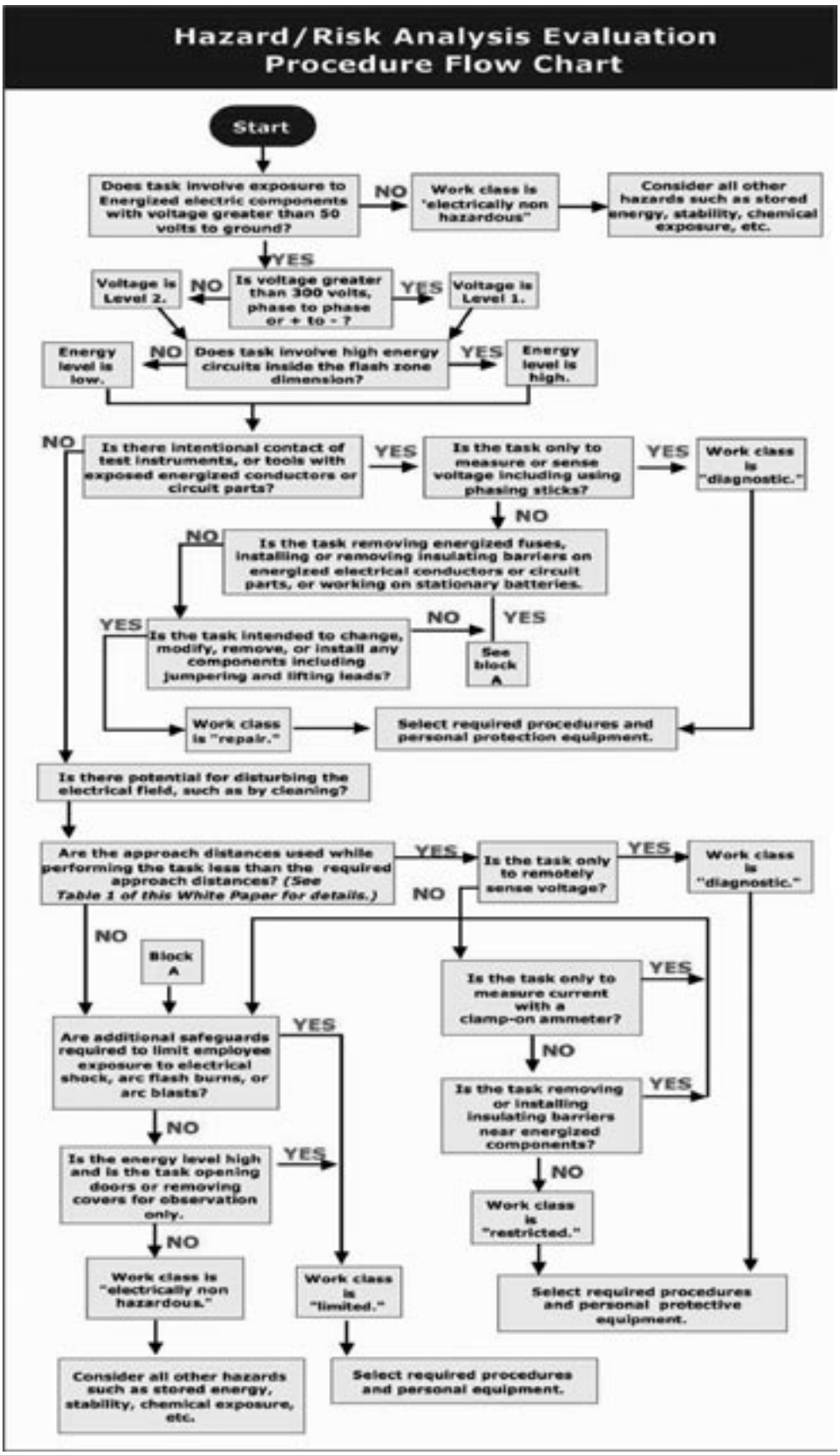
Figure 2 — Boundary Approach Diagram

(1)	(2)	(3)	(4)	(5)
Nominal System Voltage Range, Phase to Phase	Limited Approach Boundary		Restricted Approach Boundary	Prohibited Approach Boundary
	Exposed Movable Conductor	Exposed Fixed Circuit Part	Includes Inadvertent Movement Adder	
Less than 50	Not Specified	Not Specified	Not Specified	Not Specified
50 to 300	3.05 m (10 ft 0 in.)	1.07 m (3ft 6 in.)	Avoid contact	Avoid contact
301 to 750	3.05 m (10 ft 0 in.)	1.07 m (3 ft 6 in.)	304.8 rom (I ft 0 in.)	25.4 rom (0 ft 1 in.)
751 to 15 kV	3.05 m (10 ft 0 in.)	1.53 m (5 ft 0 in.)	660.4 rom (2 ft2 in.)	177.8 rom (0 ft 7 in.)
15.1 kV to 36 kV	3.05 m (10 ft 0 in.)	1.83 m (6 ft 0 in.)	787.4 mm (2 ft 7 in.)	254 mm (0 ft 10 in.)
36.1 kV to 46 kV	3.05 m (10 ft 0 in.)	2.44 m (8 ft 0 in.)	838.2 mm (2 ft 9 in.)	431.8 rom (I ft 5 in.)
46.1 kV to 72.5 kV	3.05 m (10 ft 0 in.)	2.44 m (8 ft 0 in.)	965.2 rom (3 ft 2 in.)	635 rom (2 ft 1 in.)
72.6 kV to 121 kV	3.25 m (10 ft 8 in.)	2.44 m (8 ft 0 in.)	991 rom (3 ft 3 in.)	812.8 rom (2 ft 8 in.)
138 kV to 145 kV	3.36 m (11 ft 0 in.)	3.05 m (10 ft 0 in.)	1.093 m (3 ft 7 in.)	939.8 mm (3 ft 1 in.)
161 kV to 169 kV	3.56 m (11 ft 8 in.)	3.56 m (11 ft 8 in.)	1.22 m (4 ft 0 in.)	1.07 m (3 ft 6 in.)
230 kV to 242 kV	3.97 m (13 ft 0 in.)	3.97 m (13 ft 0 in.)	1.6 m (5 ft 3 in.)	1.45 m (4 ft 9 in.)
345 kV to 362 kV	4.68 m (15 ft 4 in.)	4.68 m (15 ft 4 in.)	2.59 m (8 ft 6 in.)	2.44 m (8 ft 0 in.)
500 kV to 550 kV	5.8 m (19 ft 0 in.)	5.8 m (19 ft 0 in.)	3.43 m (11 ft 3 in.)	3.28 m (10 ft 9 in.)
765 kV to 800 kV	7.24 m (23 ft 9 in.)	7.24 m (23 ft 9 in.)	4.55 m (14 ft 11 in.)	4.4 m (14 ft 5 in.)

Figure 3 – Hazard/Risk Analysis Flow Chart

Category	PPE	Arc Rating
0	LITTLE OR NO RISK: One layer of untreated natural fiber clothing.	cal/cm²
1	Fire-resistant shirt and pants. One total layer.	4 cal/cm²
2	Fire-resistant shirt and pants. One total layer.	8 cal/cm²
3	Fire-resistant shirt and pants. One total layer.	25 cal/cm²
4	GREATEST RISK: Category 2 + multilayer flash suit. Four total layers.	40 cal/cm²

Table 1: Approach Boundaries
Approach Boundaries to Live Parts/or Shock Protection
(All dimensions are distance/from live part to employee.)


Hazard/Risk Analysis Evaluation Procedure Flow Chart
Start
Does task involve exposure to Energized electric components with voltage greater than 50 volts to ground?
NO
Work class is "electrically non hazardous"
Consider all other hazards such as stored energy, stability, chemical exposure, etc.
YES
Voltage is Level 2.
NO
Is voltage greater than 300 volts, phase to phase or + to - ?
YES
Voltage is Level 1.
Energy level is low.
NO
Does task involve high energy circuits inside the flash zone dimension?
YES
Energy level is high.
NO
Is there intentional contact of test instruments, or tools with exposed energized conductors or circuit parts?
YES
Is the task only to measure or sense voltage including using phasing sticks?
YES
Work class is "diagnostic."
NO
NO
Is the task removing energized fuses, installing or removing insulating barriers on energized electrical conductors or circuit parts, or working on stationary batteries.
YES
NO
YES
Is the task intended to change, modify, remove, or install any components including jumpering and lifting leads?
See block A
Work class is "repair."
Select required procedures and personal protection equipment.
Is there potential for disturbing the electrical field, such as by cleaning?
Are the approach distances used while performing the task less than the required approach distances? (See Table 1 of this White Paper for details.)
YES
Is the task only to remotely sense voltage?
YES
Work class is "diagnostic."
NO
NO
Block A
Is the task only to measure current with a clamp-on ammeter?
YES
Are additional safeguards required to limit employee exposure to electrical shock, arc flash burns, or arc blasts?
YES
NO
Is the task removing or installing insulating barriers near energized components?
YES
Is the energy level high and is the task opening doors or removing covers for observation only.
YES
NO
NO
Work class is "restricted."
Work class is "electrically non hazardous."
Work class is "limited."
Select required procedures and personal protective equipment.
Consider all other hazards such as stored energy, stability, chemical exposure, etc.
Select required procedures and personal equipment.

ABOUT M.C. DEAN, INC.

M.C. Dean, Inc. is one of the nation's premier design/build electrical engineering firms, offering solutions for protection of critical infrastructure and key assets, continuity of operations, and related engineering support. The firm offers full lifecycle support, from requirements analysis and design, through construction, installation, and testing, to operations and maintenance.

ARC FLASH: DO YOU UNDERSTAND THE DANGERS?

By John C. Pfeiffer, P.E., President, Pfeiffer Engineering Co Administration, U.S. Department of Energy

WHAT IS ARC FLASH?

An Arc Flash is a rapid release of energy due to an arcing fault between a phase conductor and another phase conductor, a neutral conductor or a ground.

THE RESULT:

- Rapid release of energy – a fire ball exploding outward
- Rapid release of heat – can cause incurable burns
- Blinding light - flash
- Shock/Pressure wave - Deadly, like a hammer hitting you in the chest
- Sound wave – Damage the ears – acoustic wave trauma
- Sudden spray of molten metal droplets
- Hot shrapnel flying in all directions

This type of fault is an accidental connection of energized electrical conductors and/or the earth. It is created by mechanical failures, failures of insulation, or accidentally while a person is working on an energized electrical system.

THE CAUSES:

- Spark Discharge
- Accidental touching
- Accidental dropping of tools
- Mechanical failure – part falling
- Dust & Impurities buildup
- Corrosion
- Condensation
- Insulation Failure
- Over-voltage Stress - narrow gap

This type of short circuit is the result of a brief contact of energized conductors, such as a metal part falling onto an energized circuit. The initial short is of relatively high impedance but the impedance begins to drop as the arc is produced and the air basically becomes the conductor. These arc faults are generally limited to systems where the voltage is in excess of 120 volts. At 120 volts and below, the fault normally will not sustain an arc. An arc fault is similar to the arc produced during electric welding and the fault has to be manually started by something creating the path of conduction or by a failure, such as a breakdown in insulation.

The cause of the short normally burns away during the initial flash and the establishment of highly conductive plasma that sustains the arc fault. The plasma will conduct as much energy as is available and is only limited by the impedance of the arc and the overall electrical system impedance. This massive energy discharge burns the bus bars or wiring, vaporizing the copper or aluminum and thus causing an explosive volumetric increase. The arc flash is a blast and is conservatively estimated as an expansion in volume of 40,000 to 1. This fiery explosion devastates everything in its path, creating deadly shrapnel and droplets of molten metal flying in many directions.

- When water boils, there is a volume increase of 1,670 to 1
- When copper vaporizes (boils), there is a volume increase of 67,000 to 1
- An arc flash results in a volume increase from a conservative 40,000 to 1 to as high as 67,000 to 1

The terminal of the arc is extremely hot having a temperature estimated to be in excess of 35,000°F. This is in addition to plasma of vaporizing metal having a temperature of 23,000°F. In comparison with the sun's surface that is only 9,940°F and an atomic bomb, after 0.3 seconds, reaches only 12,632°F, this arc is unbelievably hot.

• The sun's surface temperature is 9,940°F

• 0.3 seconds after an atomic bomb explodes, its core is at 12, 632°F

• The arc flash conductive plasma is at temperature of >23,000°F

• The terminal points of an arc are >35,000 °F

The high heat and volume expansion produces a pressure wave that can literally knock a person over, producing sound at a level that can damage hearing. It's a fireball with shrapnel exploding outward. Injury and fires resulting from such an event are primarily the result of the radiant heat produced and by the molten metal (1,832°F) rather than by the arc itself.

The arc fault current that is produced during an arc flash is usually much lower than the available bolted fault current that occurs during a direct short circuit. Thus, it is often below the rating/setting of the protecting circuit breaker or fuse. Unless these protective devices have been selected to handle the arc fault condition, they normally will not trip or trip fast enough to minimize the full force of an arc flash. The amount of energy produced at the point of the arc is a function of the voltage and current present as well as the time that the arc is sustained; this time is the most important part of the energy equation, every second matters greatly. The transition from the arc fault to the arc flash takes a finite time, increasing in intensity as a pressure wave develops. The challenge to protect against an arc flash is to sense the arc fault current and shut off the current in a timely manner before it develops into a serious arc flash condition.

WHY THE FOCUS ON ARC FLASH?

On a daily basis the number of arc flash incidents in the United States is greater than most electricians or engineers believe. The Chicago-based Capelli-Schellpfeffer, Inc. reports that five to 10 arc flash injuries occur a day requiring hospitalization. Severe arc flash burns can cause a slow painful death. The hot gasses produced can injure lungs and impair breathing. The very loud sound can destroy the eardrums and the blast can propel the person some distance away, often causing injury. If the person is lucky enough to be far enough away from the direct effects of the arc flash, there can be psychological effects lasting many years. These effects can result in depression, job apprehension, and family tension.

WHAT WERE THEY DOING?

They were installing a tap to a bus bar system at a hospital. The work had to be performed hot. Electricians were using insulating blankets and insulated tools. A supervisor was closely supervising every action taken. They were following all the safety rules, so what went wrong?

The supervisor used a wooden ruler to point as he directed the work. Unbeknownst to him and unfortunately for the entire crew, the ruler had a metal tip. No one knows exactly what happened but.

ELECTRICIAN 1

- 2nd Degree Burns – 40% of his body
- 3rd Degree Burns – 20% of his body
- End result – death after 11 days in intensive care

ELECTRICIAN 2

- 2nd Degree Burns – 20% of

Electrical blast burns 3 working at XXXXXXXX hospital

By JIM ADAMS
The Courier-Journal

Two men were critically injured and a third suffered burns on his hands in an electrical explosion yesterday in the basement of

The men, employees of Electric Co., were doing routine maintenance work in a small room where the building's electrical panels are housed when the explosion occurred about 7:30 a.m., said Daniel Shaw, public-relations manager for Health System.

No patients were affected, Shaw said.

Two of the men were in critical condition yesterday afternoon at University of Louisville Hospital. The hospital would not release their names, at the request of their families, but the Louisville Fire Department identified them as and

Lt. Col. Keith Milliner of the fire department said seven workers were in the basement when touched something carrying a current with a metal-tipped ruler, causing an arc and an electrical flash.

suffered second-degree burns over 40 percent of his body and third-degree burns over another 20 percent, Milliner said. suffered second-degree burns over 20 percent of his body and third-degree burns over another 20 percent.

Shaw said the third injured worker was treated at and released. Milliner identified him as and said he suffered first- and second-degree hand burns.

The ages and addresses of the workers were not available.

The explosion knocked out power to the building, but emergency generators immediately kicked on. An alarm sounded, but Shaw said no patients were moved in the hospital, formerly

He said patients probably didn't notice anything was amiss unless they happened to see firefighters arrive.

Fire crews found a haze of smoke but no fire in the basement, Milliner said. They spent about two hours trying to clear the basement of smoke.

Telephone calls yesterday to were not returned.

his body
- 3rd Degree Burns – 20% of his body
- End result – Critical Condition, Lengthy hospital stay
  Supervisor – Treated and released, off work an extended time due to the trauma of the accident

ELECTRICAL SAFETY IS THE MOST OVER-LOOKED EMPLOYEE WORK HAZARD:

- 432 work related deaths last year (Source: Department of Labor)
- Electrocution is fourth in work related fatalities with a majority of these incidents occurring at 600 volts or less.
- 7,600 disabling and non-disabling electrical injuries occur in the US each year
- OSHA published top 10 most violated standards. Electrical is now #4 on the list

The prevailing mind-set of the electrical industry and electricians is, "It won't happen to me", – famous last words.

In the early 1980s a paper titled "The Other Electrical Hazard: Electric Arc Blast Burns" by Ralph Lee was published in the IEEE Transactions on Industrial Applications. The effect of this paper was to realize the need to protect people from the hazards of arc flash.

Now four separate industry standards concern the prevention of arc flash incidents:

- OSHA 29 Code of Federal Regulations (CFR) Part 1910 Subpart S.
- NFPA 70-2002 National Electrical Code.
- NFPA 70E-2004 Standard for Electrical Safety Requirements for Employee Workplaces.
- IEEE Standard 1584-2002 Guide for Performing Arc Flash Hazard Calculations.

OSHA'S GENERAL DUTY CLAUSE:

Section 5(a)(1) of the Occupational Safety and Health Act requires an employer to furnish to its employees:

"(A) Each employer.

(1) Shall furnish to each of his employees employment and a place of employment which is free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees;"

OSHA 29 CFR 1910.303(B)(1) ELECTRICAL GENERAL REQUIREMENTS

"Examination. Electrical equipment shall be free from recognized hazards that are likely to cause death or serious physical harm to employees. Safety of equipment shall be determined using the following considerations:"

OSHA 29 CFR 1910.132(D)(1):

"the employer shall assess the workplace to determine if hazards are present, or are likely to be present, which necessitate the use of personal protective equipment (PPE). If such hazards are present, or likely to be present, the employer shall: Select, and have each affected employee use, the types of PPE that will protect the affected employee from the hazards identified in the hazard assessment;...."

NFPA 70E-2004:

"A flash hazard analysis shall be done in order to protect personnel from the possibility of being injured by an arc flash. The analysis shall determine the Flash Protection Boundary and the personal protective equipment that people within the flash Protection Boundary shall use."

NEC-2008:

"110.16 Flash Protection. Equipment such as switchboards, panel boards, industrial control panels, and motor control centers in other than dwelling occupancies, that are likely to require examination, adjustment, servicing, or maintenance while energized, shall be field marked to warn qualified persons of potential electric arc flash hazards.

The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment."

"FPN No. 1: NFPA 70E-2000, Electrical Safety Requirements for Employee Workplaces, provides assistance in determining severity of potential exposure, planning safe work practices, and selecting personal protective equipment."

"FPN No. 2: ANSI Z535.4-1998, Product Safety Signs and Labels, provides guidelines for the design of safety signs and labels for application to products."

Compliance with OSHA involves adherence to a six-point plan:

1. A facility must provide, and be able to demonstrate, a safety program with defined responsibilities.
2. Calculations for the degree of arc flash hazard.
3. Provide correct personal protective equipment (PPE) for workers.
4. Training for workers on the hazards of arc flash.
5. Appropriate tools for safe working.
6. Warning labels on equipment.

Note that the labels are provided by the equipment owners, not the manufacturers. It is expected that the next revision of the National Electric Code will require that the labels contain the equipment's flash protection boundary, its incident energy level, and the required personal protective equipment (PPE).

Companies will be cited and fined for not complying with these standards.

PERSONAL PROTECTIVE EQUIPMENT (PPE)

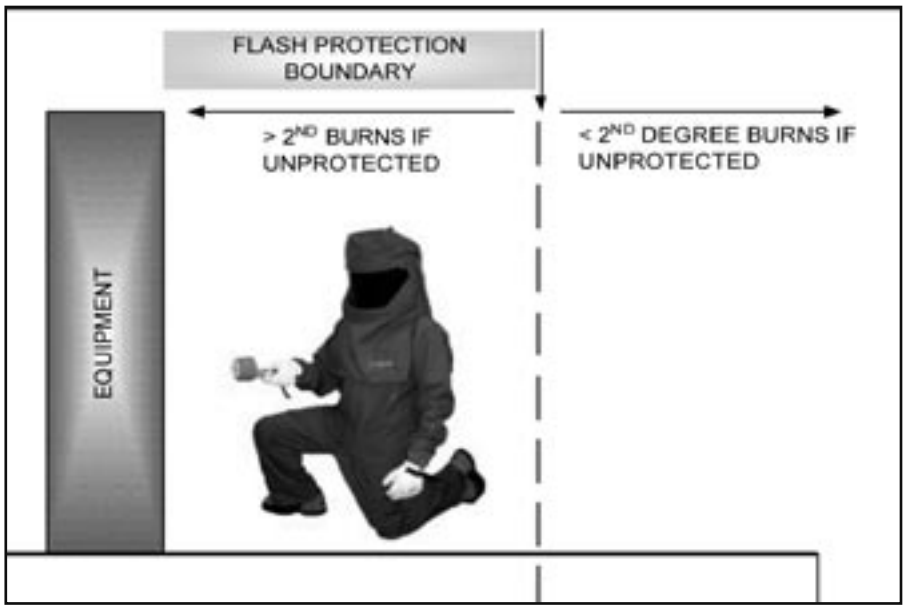
The types of personal protective equipment/clothing required for working on energized electrical equipment has been defined in NFPA 70E and is described in the following categories. Each category is further defined by other NFPA standards with respect to the functionality of each type of PPE.

Category	Cal/cm^2	Clothing
0	1.2	Untreated Cotton
1	4	Flame retardant (FR) shirt and FR pants
2	8	Cotton underwear FR shirt and FR pants
3	25	Cotton underwear FR shirt, FR pants and FR coveralls
4	40	Cotton underwear FR shirt, FR pants and double layer switching coat and pants

Cal/cm2 are the units of incident energy that the PPE can withstand. Note that a hard hat with full-face shield and the appropriate gloves are also required.

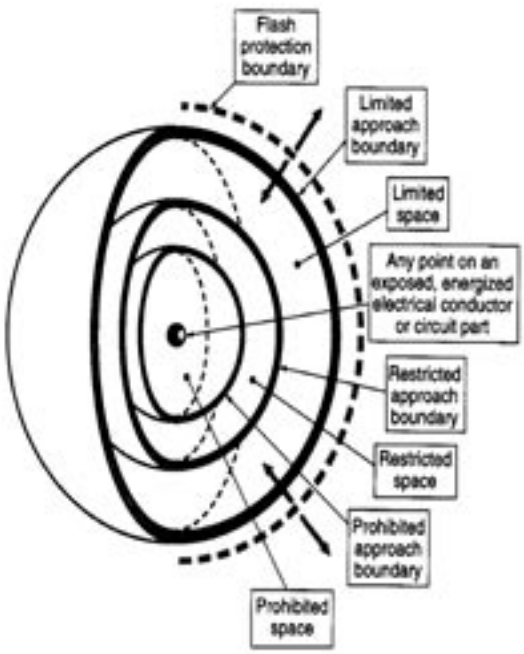
The Category 4 PPE is not intended to protect under all conditions but rather only up to a limit of 40 Cal/cm2. Many arc flashes produce energy far in excess of 40 Cal/cm2 with energy values in the hundreds of Cal/cm2.

The PPE categories only provide protection for the effects of the heat. They do not provide protection for the flying shrapnel, molten metal, pressure wave or from electric shock.



LIMITS OF APPROACH

NFPA 70E defines boundaries that correlate PPE with the type of work being preformed. The following diagram illustrates these boundaries in all directions from any point where there are exposed energized electrical conductors.



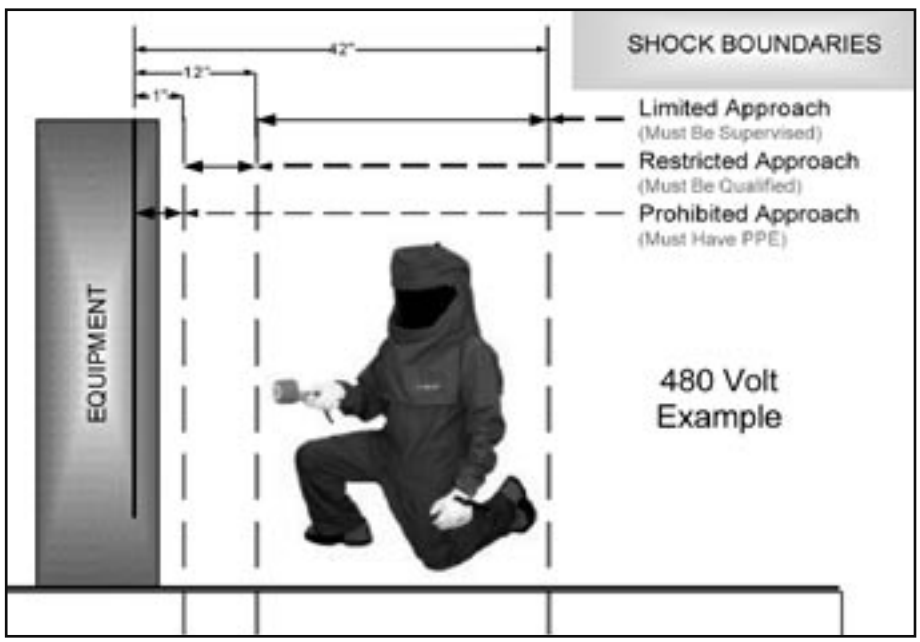
Flash protection boundary: An approach limit at a distance from exposed live parts within which a person could receive a second-degree burn if an electric arc flash were to occur.

It is generally accepted that a second-degree burn results from exposure of incident energy of 1.2 Cal/cm2

Limited Approach Boundary: An approach limit at a distance from an exposed live part within which a shock hazard exists.

Restricted Approach Boundary: An approach limit at a distance from an exposed live part within which there is an increased risk of shock, due to electrical arc over combined with inadvertent movement, for personnel working in close proximity to the live part.

Prohibited Approach Boundary: An approach limit at a distance from an exposed live part within which work is considered the same as making contact with



STEP 1

Arc Fault Current:[3]

For V < 1 kV. D.8.2(a)[4]

$\text{Log } I_a = K + 0.662 \text{ Log } I_{bf} + 0.0966 V + 0.000526 \text{ Gap} + 0.5588 (\text{Log } I_{bf}) V - 0.00304 (\text{Log } I_{bf}) \text{ Gap}$

For V > 1 kV. D.8.2(b)

$\text{Log } I_a = 0.00402 + 0.983 \text{ Log } I_{bf}$

I_a = Arc Fault Current (.7kA to 106kA)
I_{bf} = Bolted Short circuit current (3 phase symmetrical RMS kA)
GAP = Gap between conductors (13mm to 152mm)
K = -0.153 for open air
K = -0.097 for "In Box"
V = System voltage (.208 kV to 15kV)

STEP 2

Use the protective device coordination curve to determine the time to clear the fault.

STEP 3

Incident Energy (Joules/cm^2)

$En = 10^{[K1 + K2 + 1.0811 * \log(IA) + 0.0011G]}$ Normalized to 0.2 seconds and 610 mm working distance D.8.3(a)

$E = 4.184 C_f E_n (t/0.2) (619/D)^x$ Adjustable to other values of t and working distance D.8.3(c)

Joules/cm^2 = 0.2388 Cal/cm^2

E_n = Normalized Incident Energy (Joules/cm^2)
E = Incident Energy (Joules/cm^2)
K_1 = -0.729 for Open Air,
K_1 = -0.555 for In-A-Box
K_2 = 0 for ungrounded and high resistance grounded
K_2 = -0.113 for grounded systems
C_f =Calculation factor (1.5 for V < 1kV & 1.0 for V > 1kV)
G = Gap (mm)
D = Working Distance (610mm, 24 in. normal)
t = Time to clear arc (seconds)
x = Distance exponent (from table)

System Voltage (kV)	Type of Equipment	Typical Gap (mm)	Distance X-Factor
0.208 to 1	Open-air	10 – 40	2.000
	Switchgear	32	1.473
	MCCs & Panels	25	1.641
	Cables	13	2.000
>1 to 5	Open-air	102	2.000
	Switchgear	13-102	.0973
	Cables	13	2.000

the live part.

ARC FLASH EQUATIONS

The on the following page equations form the basis of the arc flash calculations. Manual calculations are very time consuming and can only be easily applied on small case studies. The only practical approach is to use arc flash analysis software.

STEPS REQUIRED FOR A FLASH HAZARD ANALYSIS

To perform an arc flash hazard analysis, data is collected about the facility's power distribution system.

The data includes the arrangement of components on a one-line drawing with nameplate specifications of every device. Also required are details of the lengths and cross sectional area of most cables. The utility should be contacted for information including the minimum and maximum fault currents that can be expected at the entrance to the facility. Once the data has been collected, a short circuit analysis is performed followed by a coordination study. The resultant data is then fed into the equations described by either NFPA 70E-2004 or IEEE Standard 1584-2004 as outlined above. These equations produce the necessary flash protection boundary distances and incident energy needed to set the minimum

PPE REQUIREMENTS

1. Collect data
2. Perform a Short-circuit Analysis
3. Perform a Coordination study
4. Perform an Arc Flash study
5. Perform a Sensitivity Study
6. Select PPE
7. Label Equipment
8. Provide training

SHORT-CIRCUIT STUDY

The short-circuit study is based on a review of a facility's one-line drawings. The drawings must be created if they do not exist, and

field-verified if they do exist. Maximum available fault current is calculated at each significant point in the system. Each overcurrent protective device is analyzed to determine whether it is appropriately designed and sized to interrupt the circuit in the event of a bolted type of short circuit. Next, the associated equipment is reviewed to insure that the bus bar is adequately braced to handle the available fault current.

The normal short circuit study is concerned with fault interruption and the protection of equipment from the faults. Thus, the maximum available short circuit current from the utility is needed. Also, many cable lengths (impedances) are assumed to be very short or even zero. This provides a worse case analysis.

In the above the engineer always strives to produce results that are on the safe (more conservative) side.

Since, the calculated short circuit current is the basis of calculating the arc fault current, it has been found that this conservative approach is inappropriate when the intent is to produce an arc flash hazards analysis.

In the study for the arc flash hazards analysis the engineer needs to be more detailed. First, the engineer needs to obtain both the maximum and minimum available short circuit current from the utility. This is often very difficult to obtain. Often all that is available is the expected short circuit current. Next, cable impedance data needs to be entered into the study using actual measured cable lengths for major cables such as the primary feeders and main branch circuits. Estimated lengths can be used for smaller feeders and branch circuits. This approach will result in a more realistic short circuit current to base the arc flash hazards analysis on.

> 5 to 15	Open-air	13-153	2.000
	Switchgear	153	0.973
	Cables	13	2.000

Or

Incident Energy - For system voltages > 15kV

$E = 2.124 \times 10^6 \, V \, I_{bf} \, (1/D^2)$ D.8.4

E = Incident Energy (Joules/cm^2)
V = System Volts (kV)
I_{bf} = Bolted Short circuit current (3 phase symmetrical RMS kA)
D = Working Distance (610mm)
t = Time to clear arc (seconds)
x = Distance exponent (from table)

$E = 793 \, D^{-2} \, V \, I_{bf} \, t$
E = Incident Energy (Cal/cm^2)
D = Working Distance (24 in.)

OR

Incident Energy (Cal/cm2) – In The Box:[5] (=< 600v)

$E_{MB} = (1038.7 \, D_b^{-1.4738} \, T_A) \, (.0093 \, F^2 - .3453 \, F + 5.9675)$ D6.2(a)

E_{MB} = Maximum 20 in. cube box incident energy, Cal/cm^2
D_b = Distance from arc in inches
T_A = arc duration in seconds
F = Short circuit current, kA (for the range of 16 kA to 50kA)

Incident Energy (Cal/cm^2) – Open Air:[6] (=< 600v)

$E_{MA} = (5271 \, D_A^{-1.9593} \, T_A) \, (.0016 \, F^2 - .0076 \, F + 0.8938)$ D.6.1(a)

E_{ma} = Maximum open arc incident energy, Cal/cm^2
D_A = Distance from arc in inches (for distances 18in. and greater)
T_A = Arc duration in seconds
F = Short circuit current, kA (for the range of 16 kA to 50kA)

STEP 4

Flash Protection Boundary

D_B = Distance from the Arc (mm)

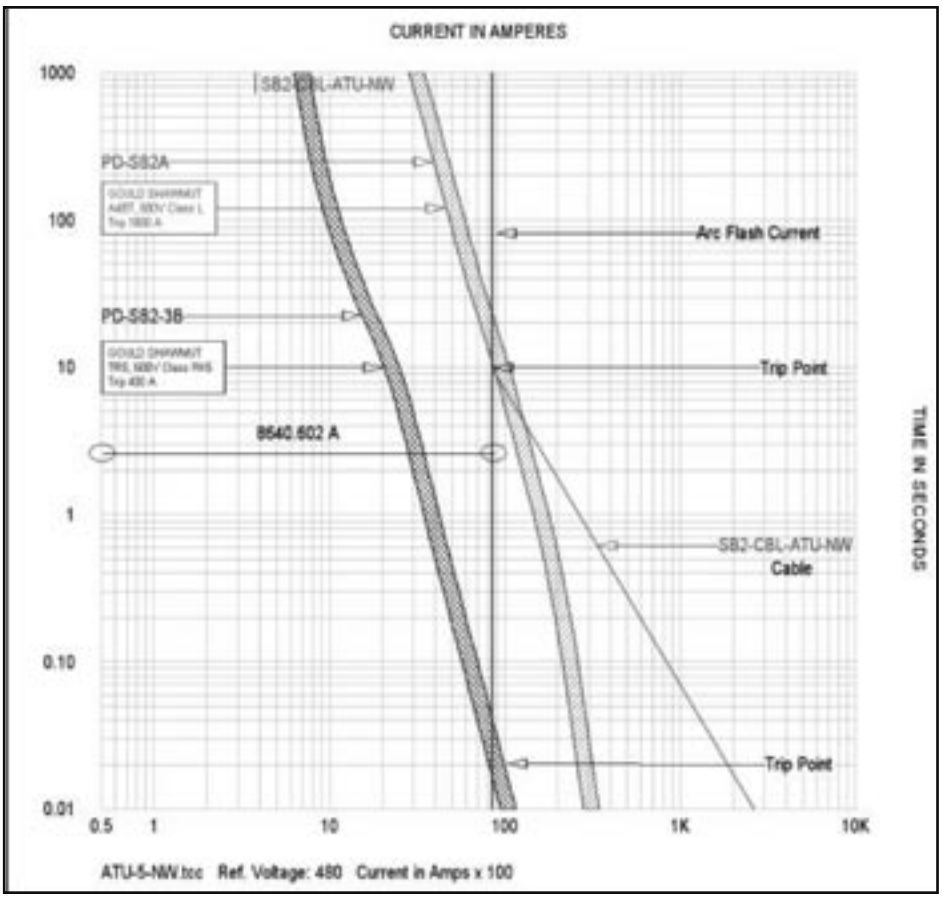
$D_B = [4.184 \, C_f \, E_n \, (t/0.2) \, (610^x/E_b)]^{1/x}$ Empirically derived D.8.5(a)

$D_B = [2.142 \times 10^6 \, V \, I_{bf} \, (t/E_b)]^{1/2}$ Theoretically derived D.8.5(b)

E_b = Incident Energy at the boundary distance (J/cm^2) for desired incident energy level, i.e. 5 J/cm^2 or 1.2 Cal/cm^2

OR

D_B = Distance from the Arc (in)



COORDINATION STUDY

A coordination study is the examination of the electrical system and available documentation with the goal of ensuring that over-current protection devices are properly designed and coordinated. Over-current protective devices are rated, selected and adjusted so only the fault current carrying device nearest the fault opens to isolate a faulted circuit from the system. This permits the rest of the system to remain in operation, providing maximum service continuity. The study consists of time-current coordination curves that illustrate coordination among the devices shown on the one-line diagram. Note that protective devices are set or adjusted so that pickup currents and operating times are short but sufficient to override system transient overloads such as inrush currents experienced when energizing transformers or starting motors.

For an arc flash hazards analysis, the overcurrent protective device data is used to determine fault-clearing times based upon the arc fault current rather than a short circuit. The length of time the arc exists along with the amount of arc fault current is used to calculate the incident energy level.

ARC FLASH HAZARD ANALYSIS AND SENSITIVITY STUDY

The arc flash analysis uses the arc fault current calculated from the bolted fault current determined in the short circuit analysis. This arc fault current is used along with the over-current protective device fault clearing time based upon the arc flash current. Together these two values, time and current, determine the incident energy level and arc fault boundary distances.

Once the data is prepared and a flash hazard analysis has been performed, most likely it will be discovered that category 4 PPE will be required in many places. This is most unfortunate as this type of PPE is very unwieldy to ware, hot in the summer, could be costly in terms of time taken to perform work and could potentially results in mistakes.

Prior to the new arc flash regulations, coordination studies were targeted at reliability with all settings adjusted towards the high side, i.e. minimize nuisance trips. Compliance with the new arc flash regulations means that not only does the coordination study need to be more accurate but it also needs to take into account the fact that the arc fault current is less than the bolted fault current. And that the clearing times of overcurrent circuit protection devices need to be fast under arc fault conditions in order to minimize energy releases.

The data can be used to perform a sensitivity study, to adjust breaker/fuse characteristics, and to lower the PPE requirement. To achieve this goal, the existing breakers may need to be replaced, generally by their more modern counterparts. Old breakers have relatively slow reaction times and will trip at too high a current. To limit the arc flash hazard, the breakers are adjusted to trip earlier than before. It is expected that the outcome of this sensitivity study, when implemented, may result in most category 4 PPE requirements being decreased to category 1 or 2. The catch: can you reduce the PPE requirements enough without resulting in more nuisance trips?

THE PROBLEMS

Now that the hazards associated with arc flash have been brought to our attention, we face the problem of trying to eliminate or at least reduce those hazards. The following discusses some of these problems and the subtleties in implementing corrective actions.

There are several problems in dealing with Arc Flash Analysis:

1. Being overly conservative in your short circuit analysis may result in the required PPE protection category being set at a level higher than necessary.

CATEGORY 4 PPE

The figure to the right is of a person in a full Category 4 suit. This suit will provide the necessary protection, but it is cumbersome to work in, it is hot, and it provides poor visibility.

The suits will make many tasks very difficult, if not impossible, to perform. Because of their restrictions to vision and movement, they may even make some tasks more dangerous. There are definitely times when this type of protection is both necessary and required, but being overly conservative will result in excessive stress to workers and unacceptable time to make repairs or adjustments.

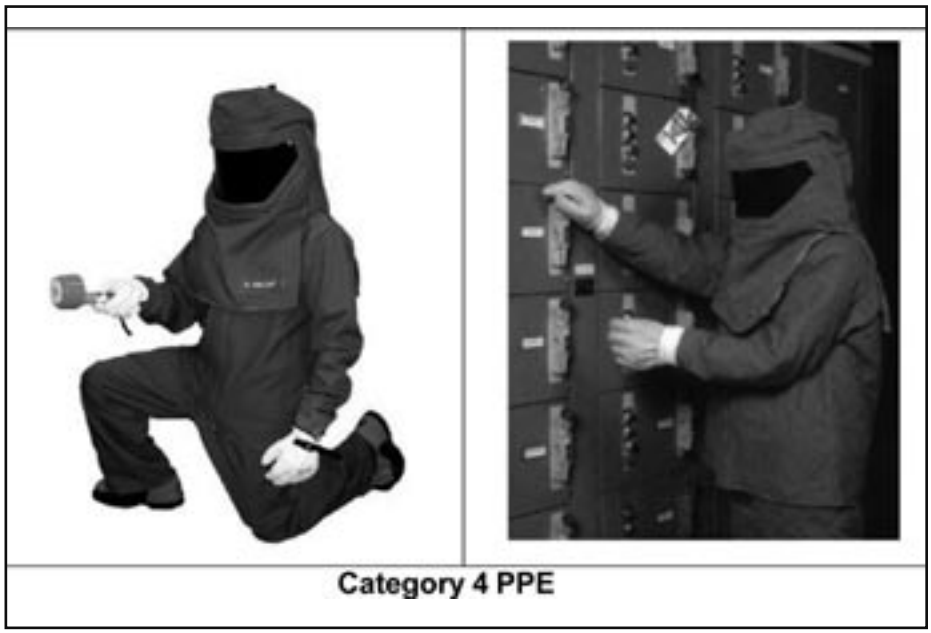
2. Relying upon quick analysis methods can expose you to unexpected liabilities. There are a number of shortcuts being offered by individuals and companies that can have disastrous results. Be sure that your methods will stand up to analysis and peer review.

Cure-all solutions are being promoted, such as the installation of current-limiting fuses. Pfeiffer Engineering is a firm believer in the use of fuses, particularly current-limiting types, but as will be shown below, they are not always the answer. They are definitely not a quick fix solution.

3. Being overly conservative when performing a short circuit analysis results in the misapplication of circuit protection equipment which, in turn, has the consequence of calculated arc flash levels being higher than they actually are.

4. The calculated bolted fault or short circuit current is a worst-case calculation that assumes very low short circuit impedance. It is a short circuit connection based upon two conductors being bolted together to form the short. In reality, most short circuits are less than ideal, resulting in fault currents that are less than the calculated bolted short circuit condition.

5. On the other hand, the arc fault should be a more predictable occurrence. The arc fault calculations assume that there is a physical gap between conductors that was bridged by something resulting in the formation of an arc. Once the arc is formed and plasma is produced, the arc current should closely approximate the calculated fault levels. The arc fault calculations are an approximation based upon research and testing similar to the short circuit analysis methods. They are not exact and therefore one needs to be careful when using the results.



Category 4 PPE

SOLUTION

The solution is to first perform, as accurately as practical, a short circuit analysis. The goal for most people performing a short circuit analysis has always been to err toward the conservative. For example, when a cable length is needed, it is the practice to always use the shortest practical value, which would result in higher calculated short circuit current values. When the public utility is contacted, it is the practice to only ask for the worse case short circuit value.

The overall result is that the short circuit values are always calculated on the high side. When doing a short circuit analysis for sizing the interrupting capability of protection equipment, this is the best practice.

But, it is not the best practice when evaluating equipment for arc faults and establishing PPE requirements. This is an extremely significant, and quite non-intuitive, situation.

Arc fault current (Ifc) is derived from the available bolted short circuit or fault current (Isc) and is always substantially less than its corresponding short circuit current. The IEEE has established formula for calculating (estimating) the Ifc and they provide a spreadsheet. The following are example results from using their formula:

Bolted Fault Current @ 480 V	Arc Fault Current
10 Ka	= 6.56 kA
20 Ka	= 11.85 kA
30 Ka	= 16.76 kA
40 Ka	= 21.43 Ka

WHAT IS NOW IMPORTANT IS TO OBTAIN:

1. The expected maximum (worst case) bolted short circuit current.

2. The minimum and maximum voltage to the facility.

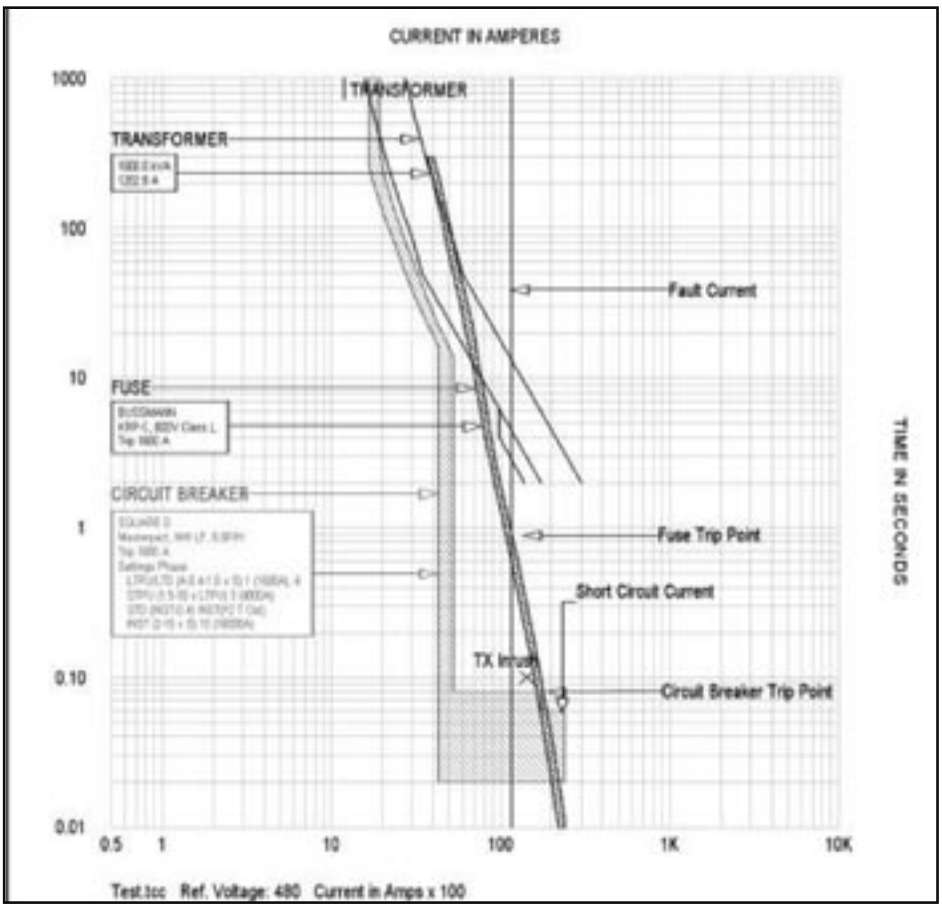
3. The minimum expected short circuit current.

Also needed are definitions of the operating modes of the facility such as:

1. What are the minimum and maximum motor loads expected during normal operation and off-hour operation.

2. Variation in the sources of supply to the plant, such as alternate feeders or co-generation.

The data from the public utility and the determination of the facility's modes



of operation should be converted into the maximum and minimum arc fault current at various locations in the plant. These results are applied to protective device coordination studies, where the protective devices are evaluated, and adjusted, if necessary, allowing the proper PPE categories to be determined.

The following coordination curve illustrates the point:

The figure above shows the coordination curve for the secondary of a 1000 kVA 480 V transformer. The curve shows two types of secondary protection, a fuse and a circuit breaker, each selected based upon the National Electrical Code requirements. The fuse is a KRP -C 1600A and the circuit breaker, "CB", is one with an electronic trip, such as the Square D Masterpack circuit breaker.

All transformers limit the amount of fault current that can pass through the transformer, a function of the transformer's impedance. The coordination curve shows a line for the Isc, the maximum short circuit current that can pass through this transformer (24,056 amps). The Isc value used assumes that there actually is sufficient current available at the primary to provide 24,056 amps on the secondary.

Based upon the IEEE formula, the calculated Arc Fault current Ifc is 11,701 amps. Using these two currents and the coordination curve, one can estimate the time the circuit breaker and the fuse will take to clear the fault.

BOLTED FAULT CONDITION:

Fuse clears in	0.02 seconds
Circuit Breaker clears in	0.08 seconds

ARC FAULT CONDITION

Fuse clears in	0.90 seconds
Circuit Breaker clears in	0.08 seconds

From these current levels and clearing times, the PPE category can be determined.

E_{mb} (Maximum in cubic box incident energy)

Fuse	36 Cal/cm^2	Category 4 PPE
Circuit Breaker	2.5 Cal/cm^2	Category 1 PPE

Clearly, in this example the circuit breaker outperforms the current-limiting fuse resulting in a much lower "worker friendly" PPE requirement.

In the above example both the arc fault current and the bolted fault current are less than the current-limiting point for the fuse, which is approximately 28,000 amps. Thus, there is no current-limiting effect from using the fuse. Current-limiting fuses often do provide additional protection and they are very good devices but they must be applied properly. In this example, the circuit breaker provides the best protection.

Studying this example further, let us assume that the fuse and the circuit breaker are at the main disconnect of a facility and the facility is served by a much larger transformer where the worst-case bolted short circuit current as reported by the utility is 60,000 amps. Under this condition, the arc fault current would be 30,300 amps. In this case, the fuse would open in 1/4 cycle and would limit the fault current.

The Emb would equal 1.15 Cal/cm^2, which falls under a category 0 PPE.

In the next example, we have a fuse and a circuit breaker protecting a 125 Hp motor. The fuse is a LLSRK 200 A and the circuit breaker, "CB", is one with an electronic trip, such as the Square D Masterpack circuit breaker.

There are three Arc Fault currents analyzed.

Point 1	
Arc Fault Current	1600 Amps
Bolted Fault Current	3200 Amps
Point 2	
Arc Fault Current	1400 Amps
Bolted Fault Current	2400 Amps
Point 3	
Arc Fault Current	1100 Amps
Bolted Fault Current	1600 Amps

Results:

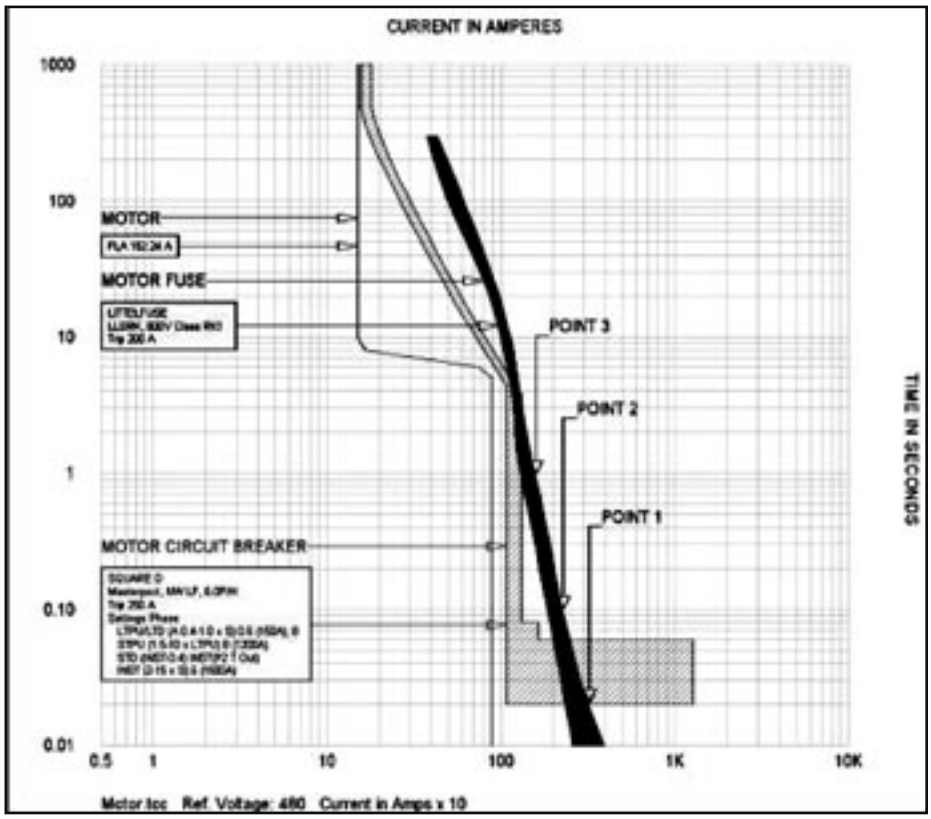
Point 1

Circuit Breaker clears in	.06 seconds	4.57 Cal/cm^2	PPE Cat. 2
Circuit Breaker clears in	.06 seconds	4.57 Cal/cm^2	PPE Cat. 2
Fuse clears in	.02 seconds	1.45 Cal/cm^2	PPE Cat. 1
Point 2			
Circuit Breaker clears in	.06 seconds	4.57 Cal/cm^2	PPE Cat. 2
Fuse clears in	.1 seconds	7.62 Cal/cm^2	PPE Cat. 2
Point 3			
Circuit Breaker clears in	.06 seconds	4.78 Cal/cm^2	PPE Cat. 2
Fuse clears in 1	.0seconds	79.8 Cal/cm^2	PPE Cat. > 4

At an arc fault current of 4000 amps, the fuse will begin to current-limit and will open the circuit in 1/4 cycle reducing the PPE category to 0.

The three points analyzed show that a relatively small change in calculated bolted fault current has a major effect on the calculated arc fault current. This situation could easily lead to the misapplication of circuit protection equipment or inappropriate adjustment of it. It should also be noted that as the calculated arc fault current is reduced, the clearing time increases, resulting in the incident energy level increasing and thus, the PPE requirement increases.

In reality, the arc current is primarily effected by facility operating conditions, i.e. motor contribution and changes in the fault current coming from the utility. The examples illustrate that the accuracy required when calculating short currents has to be improved over traditional methods. Both reliability and arc fault conditions must now be considered when performing coordination studies.



THE RISK

In a study of 33 plants with 4892 busses or switch points under 600 volts, the median incident energy was only 2.1 Cal/cm^2, however many busses had quite high incident energy levels:

- 24% of busses over 8 Cal/cm^2 PPE 2
- 12% of busses over 40 Cal/cm^2 PPE 4
- 5% of busses over 85 Cal/cm^2

Deadly – no protection

- 1% of busses over 205 Cal/cm^2

Deadly – no protection

Risks to personnel include:

- Burns
  - Just Curable Burn Threshold: 80°C/175°F (0.1 sec.)
  - Incurable Burn Threshold: 96°C/205°F (0.1 sec.)
- Damaging sound levels
- High pressure

- 720 lbs/ft^2 eardrums rupture
- 1728 to 2160 lbs/ft^2 lung damage

WHAT HAPPENS IF SOMEONE GETS INJURED OR WORSE?

The lawyers have a field day:

- The problem is now well documented
- Its in the standards now
- Complete adherence is not mandatory but the lawyers don't care.

Do we have any outs?

- The facility owner is primarily responsible.

WHAT SHOULD YOU DO?

For starters, you should at least educate your employees about the hazards, and determine the level of arc flash hazard at the worst locations, but this is not enough. OSHA and the NEC do have requirements that MUST be met. They set the "standard of care". This hazard is now a recognized hazard, which means that you can be held liable if you ignore the hazards and don't comply.

You will be found in "Breach of Duty" to protect if an arc flash happens.

OSHA enforces NFPA 70E under the "General Duty Clause". A section of the US Occupational Safety and Health Act of 1970, known as the "General Duty Clause," requires employers to furnish a workplace which is free from recognized hazards which may cause or are likely to cause death or serious physical harm. OSHA 29 CFR 1910.303

SO WHY SHOULD YOU DO ANYTHING?

Legal and moral obligations and consequences.

OSHA fines:

Individuals	- up to $250,000
Companies	- up to $500,000
Imprisonment	- up to 6 months in jail

The cost in time, stress and dollars to defend a legal action against you, is severe.

WE ONLY USE CONTRACTORS, SO WHY WORRY?

"All of our contracts have Hold Harmless clauses, which makes the contractor responsible to defend us in the event their employees get injured. So we are in the clear."

WRONG!

The facility manager is responsible to Warn of Arc Flash hazards. If a contractor's employee is injured or killed because of your lack of providing the mandated warnings and protection, you can be found liable.

And you may have to pay all the costs. You may have "breached your duty" to protect. Remember. This is a recognized hazard.

CONCLUSIONS

1. Arc Fault Analysis is actually Risk Management. There are basically three choices:

• Be very conservative and require PPE 4 in most cases resulting in higher maintenance cost.

• Do nothing and suffer the consequences (pay later).

• Perform the necessary analysis and make adjustments to reduce the arc fault conditions resulting in reduced PPE requirements.

2. A reduction in bolted fault current and thus a reduction in arc fault current can actually result in a worse situation. In the motor example above, an arc fault current reduction from 4000 amps to 1800 amps resulted in an increase in arc fault energy from 0.6 Cal/cm^2 to 78.8 Cal/cm^2, exactly the opposite one would expect before doing the math. In terms of the above example coordination curves, this occurs because the arc fault current moves from the instantaneous portion at the bottom of the coordination curve to a point higher up, incurring a time delay before the device trips.

3. Overly conservative short circuit analysis will result in bolted short circuit numbers that may well result in the misapplication of circuit protection equipment.

4. It is very important to obtain the minimum available short circuit current as well as the maximum short circuit current from the electric utility. Voltage fluctuations in the plant supply should be considered when developing the short circuit calculations. The arc fault calculations need to be evaluated at more than just the worst case and the minimum case conditions. In the example above, a reduction in the arc fault current actually resulted in worse conditions. This represents a subtle, but extremely significant, change in the methodology of short circuit analysis.

5. Apart from the fines, nominal compliance with the regulations will cause workers to have to wear cumbersome PPE. This will result in little or no high voltage maintenance being performed, eventually compromising safety, equipment operation, and ultimately productivity. Arc flash is a risk management issue.

6. Have a registered professional engineering firm perform the calculations for arc flash hazards for the devices in your facility and have them recommend any necessary plans that, when executed, would result in the lowest category of PPE being required.

NOTE:

Short circuit analysis is based upon a number of assumptions, any or all may change over time;

1. Available short circuit current from the utility may vary, particularly in areas where there has been a significant expansion of, or change to, the electrical systems.

2. The number of motors running at the time of a fault affects the amount of short circuit current and arc fault current available (motor contribution).

3. The facility voltage often varies as a function of time of day. The utility is often more loaded during the day.

Similarly, the arc fault may also be affected by variations in any of the following:

1. The available short circuit current.

2. Dirt buildup in the equipment that may affect the conductive path.

3. Moisture (humidity).

4. Circuit supply voltage.

5. Amount of motor contribution during a fault

Author

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CREATING A LOCKOUT /TAGOUT PROGRAM

Excerpts from Oklahoma State University Program for Control of Hazardous Energy

PURPOSE

The purpose of this program is to establish procedures for affixing appropriate lockout or tagout devices to energy-isolating devices, and to otherwise disable machines or equipment to prevent unexpected energization, start-up or release of stored energy in order to prevent injury to employees.

LIST OF TERMS

Affected Employee

An employee whose job requires them to operate or use a machine or piece of equipment on which servicing is being performed under lockout or tagout, or whose job requires them to work in an area in which such servicing or maintenance is being performed.

Authorized Employee

A person who locks or implements a tagout system procedure on machines or equipment to perform the servicing or maintenance on that machine or equipment. An authorized employee and an affected employee may be the same person when the affected employee's duties also include performing maintenance or service on a machine or piece of equipment which must be locked, or a tagout system implemented. Energy Source: Any source of electrical, mechanical, hydraulic, pneumatic, chemical, thermal, or other energy.

Lockout

The placement of a lockout device on an energy-isolating device, in accordance with an established procedure, ensuring that the energy-isolating device and the equipment being controlled cannot be operated until the lockout device is removed. Lockout Device: A device that utilizes a positive means, such as a lock, to hold an energy-isolating device in the safe position and prevent the energizing of a machine or piece of equipment.

Normal Production Operations

The utilization of a machine or piece of equipment to perform its intended production function.

Primary Authorized Employee

The authorized employee who has been vested with responsibility for a set number or group of employees performing service or maintenance on machines or equipment subject to lockout or tagout procedures.

Servicing and/or Maintenance

Workplace activities such as constructing, installing, setting up, adjusting, inspecting, modifying, and maintaining and/or servicing machines or equipment. These activities include lubrication, cleaning or unjamming of machines or equipment, and making adjustments or tool changes where the employee may be exposed to the unexpected energization or start-up of the equipment or release of hazardous energy.

Tagout

The placement of a tagout device on an energy-isolating device, in accordance with an established procedure, to indicate that the energy-isolating device and the equipment being controlled may not be operated until the tagout device is removed.

TECHNIQUES

Implementation of the lockout or tagout system shall be performed only by authorized employees. Affected employees shall be notified by heads of departments, or their designated representatives, of the application and removal of lockout or tagout devices. Notification shall be given before the controls are applied, and after they are removed from the ma-

chine or equipment.

The established procedure for the application of energy control shall cover the following elements and actions and shall be done in the following sequence:

1. Preparation for shutdown: Before an authorized or affected employee turns off a machine or piece of equipment, they shall have knowledge of the type and magnitude of the energy, the hazards of the energy to be controlled, and the method or means to control the energy.

2. Machine or equipment shutdown: An orderly shutdown must be utilized to avoid any additional or increased hazard(s) to employees as a result of equipment de-energization.

3. Machine or equipment isolation: All energy-isolating devices that are needed to control the energy to the machine or equipment shall be physically located and operated in such a manner as to isolate the machine or equipment from the energy source(s).

4. Lockout or tagout device application: Lockout or tagout devices shall be affixed to each energy-isolating device by authorized employees. Lockout devices, where used, shall be affixed in a manner that will hold the energy in a "safe" or "off" position. Tagout devices, where used, shall be affixed in such a manner as will clearly indicate that the operation or movement of energy- isolating devices from the "safe" or "off" position is prohibited.

Where tagout devices are used with energy-isolating devices designed with the capability of being locked, the tag shall be fastened at the same point at which the lock would have been attached.

Where a tag cannot be affixed directly to the energy-isolating device, the tag shall be located as close as safely possible to the device, in a position that will be immediately obvious to anyone attempting to operate the device.

5. Stored Energy: Following the application of lockout or tagout devices to energy-isolating devices, all potentially hazardous stored energy shall be rendered safe. If there is a possibility of re-accumulation of stored energy to a hazardous level, verification of isolation shall be continued until the servicing or maintenance is completed, or until the possibility of such accumulation no longer exists.

6. Verification of Isolation: Prior to starting work on machines or equipment that have been locked out or tagged out, the authorized employee shall verify that isolation and de-energization of the machine or equipment has been accomplished.

7. Release from Lockout or Tagout: Before lockout or tagout devices are removed and energy is restored to the machine or equipment, procedures shall be followed and actions taken by the authorized employee(s) to ensure the following:

• The Machine or Equipment: The work area shall be inspected to ensure that nonessential items have been removed and that machine or equipment components are operationally intact.

• Employees: The work area shall be checked to ensure that all employees have been safely positioned or removed. Before lockout or tagout devices are removed and before machines or equipment are energized, affected employees shall be notified.

8. Lockout or Tagout Device Removal: Each lockout or tagout device shall be removed from each energy isolating device by the employee who applied the device.

Exception: When the authorized employee who applied the lockout or tagout device (installer) is not available to remove it, that device may be removed under the direction of the installer's immediate supervisor. Specific training and procedures for such removal shall be provided by each department involved in lockout or tagout operations. The procedures and training shall be documented.

The documentation shall demonstrate that safety equivalent to the original process of having only the installer remove the device is maintained. The specific procedure shall include at least the following elements:

• Verification by the immediate supervisor that the employee who applied the device is not at the facility,

• Making all reasonable efforts to contact the authorized employee to inform them that his/her lockout or tagout device has been removed, and

• Ensuring that the authorized employee has this knowledge before they resume work at the facility.

9. Testing or Positioning of machines, equipment, or components thereof: In situations where lockout or tagout devices must be temporarily removed from the energy-isolating device and the machine or equipment energized to test or position the equipment or component thereof, the following sequence of actions shall be followed:

• Clear the machine or equipment of tools and materials.

• Remove employees from the machine or equipment area.

• Remove the lockout or tagout devices.

• Energize and proceed with testing or positioning.

• De-energize all systems and reapply energy control measures to continue the servicing and/or maintenance.

10. Outside Personnel (contractors, etc.): Whenever outside servicing personnel are to be engaged in activities covered by the scope and application of this program, the designated Oklahoma State University representative and the outside employer shall inform each other of their respective lockout or tagout procedures. The designated Oklahoma State University representative shall ensure that his/her personnel understand and comply with restrictions and prohibitions of the outside employer's energy control procedures. If the outside employer has no documented lockout or tagout procedures, they shall ensure that their personnel understand and comply with the procedures established in this program.

11. Group Lockout or Tagout: When servicing and/or maintenance is performed by a crew or department, they shall utilize a procedure that affords their employees a level of protection equivalent to that provided by the implementation of a personal lockout or tagout device. This shall be accomplished by:

• The application of a multi-lock accepting device by the primary authorized employee to the energy- isolating device.

• The primary authorized employee attaching his/her lock to the multi-accepting device.

• Each authorized employee shall affix a personal lockout or tagout device to the multi-lock accepting device when they begin work, and shall remove those devices when they stop working on the machine or equipment being serviced or maintained.

• The primary authorized employee removing his/her lock and the multi-lock accepting device when all service or maintenance has been completed.

12. Shift or Personnel Changes: To insure the orderly transfer of lockout or tagout devices between off-going and on-coming employees and minimize exposure to hazards from unexpected energization, start-up of the machine or equipment, or release of stored energy, these procedures shall be followed:

• The on-coming personnel shall notify the off-going personnel that they are ready to begin work on the machine or equipment.

• All lockout and/or tagout devices attached to the machine or equipment by the off-going personnel shall be removed and immediately replaced with like devices by the on-coming authorized personnel.

• The primary authorized employee shall insure that all pertinent co-ordination between off-going and on-coming personnel has been completed before the on-coming authorized personnel begin work on the machine or equipment and that all necessary energy has been rendered safe.

10 Steps Of An Effective Arc Flash Hazard Safety Program

By EasyPower, ESA Inc.

1. ACKNOWLEDGE

Become aware of arc flash hazard dangers through industry events and resources such as the NFPA, IEEE, trade publications, and on-line resource centers.

Arcing faults release dangerous levels of radiant heat energy and arc blast pressure waves capable of causing severe, and possibly fatal, injuries.

2. EVALUATE

The OSHA General Duty Clause makes it clear that the employer has an obligation to protect workers from known hazards. In addition, an effective Arc Flash and Electrical Safety Program can save millions of dollars in losses from a single arc flash or shock event. Developing an economic benefit case will help you obtain management buy-in and funding.

The incurred costs can include:

- Treatment for victims
- Legal defense fees
- OSHA Fines
- Lost worker productivity
- Workers' compensation premium increases
- Lost facility production/ downtime

3. DEFINE

Define specific and measurable goals.

Determine the gap between your current electrical safety program and your goals. Develop an action plan, budget, and timeline. Outline the steps necessary to provide tangible safety improvements in your facility that will comply with NFPA and OSHA Safety Standards.

These standards include:

- Up-to-Date Electrical Drawings [NFPA 70E Article 120.1(F)(1), 205.2] used for planning work, verifying voltages, alternate sources, capacitor back feeds, etc.
- Short Circuit/Equipment Duty Analysis [400.5, 400.6] required to ensure all equipment is properly rated to withstand and interrupt the available short circuit current.
- Protective Device Coordination [410.9] required to ensure that all protective devices will operate properly on the available short circuit current in the system.
- Arc Flash Hazard Analysis

4. ANALYZE

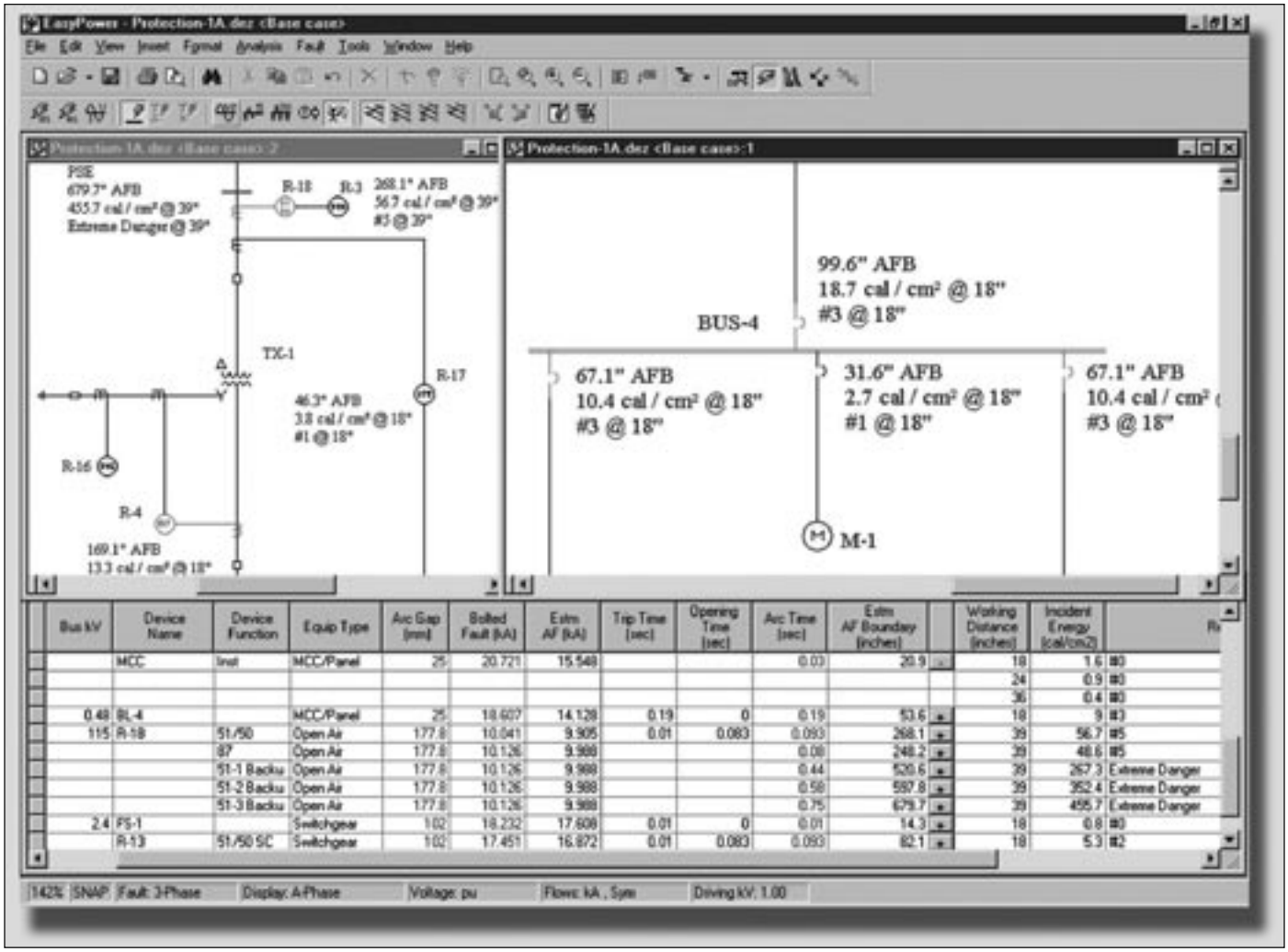
Analyze your electrical power system to determine accurate Incident Energy, PPE Requirements, Flash Hazard Boundary, Shock Hazard, and the Limited, Restricted and Prohibited Approach Boundaries for Shock Hazard in accordance with NFPA 70E Articles 130.1, and 103.3.

Arc flash hazard evaluation should include the following steps:

A) Develop accurate one-lines that help workers identify equipment voltage levels, sources, tie breakers, and various system configurations that impact hazard calculations. These will also be used for planning purposes to determine back feeds and energized sources. Article 120.1(F)(1), 205.2

B) Field data collection of electrical equipment nameplate parameters. These parameters in conjunction with the EasyPower software library provide a comprehensive model and database of the electrical system to perform all types of analysis.

C) Perform short circuit and equipment duty calculations to ensure all equipment is properly rated to withstand and interrupt the available short circuit current. Improperly rated equipment can result in catastrophic failure. Article 400.5, 400.6



D) Perform protective device coordination (circuit breakers, fuses, protective relays, etc.) to ensure that each device will operate properly on the available bolted and arcing short circuit current.

Proper protective device selection and coordination (settings) will reduce arc flash hazards and worker exposure, increasing plant reliability. Article 410.9

E) Perform arc flash hazard calculations based on IEEE-1584 or NFPA 70E formulas and guidelines. Worst-case calculations should be determined for all equipment. Article 130.1, 130.3

F) Create labels from EasyPower to provide Article 400.11 compliance and ensure worst-case hazards are posted and visible for all equipment (Refer to Section 5, Label). Article 400.11 EasyPower software will create your one-line diagrams, document the electrical system parameters, accurately perform the required 70E calculations, and evaluate options to reduce hazards and risk to personnel. EasyPower's detailed analysis can prevent the mistakes of over or under protection common to other methods of analysis, increasing electrical system reliability.

5. LABEL

ESA recommends the use of high quality UV resistant vinyl la-

bels. ANSI Z535 compliant labels are required. Always label for the worst-case conditions in the equipment (Switchboard, Motor Control Center, etc.) based on the arc flash hazard calculations (Refer to Section 4, Analyze), then utilize Energized Work Permits to reduce the energy and PPE requirements based on the work task and a job hazard risk analysis. Article 110.7(G)

6. PPE

PPE (personal protective equipment) is your last line of defense should an accident occur; thus, the choice of appropriate PPE for the hazards involved is essential. The evaluation of PPE should be completed in conjunction with an arc flash hazard study using EasyPower

(Refer to Section 4, Analyze). NFPA 70E contains several categories of PPE to address the hazards. Since it can be confusing and costly to obtain gear for protection in each of these divisions, an arc flash hazard study will help you manage PPE into a limited number of categories avoiding unnecessary confusion and expense.

7. WORK PERMITS

Energized Work Permits are required by NFPA 70E Article 130.1 for all energized work above 50 volts (except for diagnostics). Work Permits are a key aspect of NFPA 70E. They document the safe work practices and procedures used, job briefing and planning, arc flash hazards, and the PPE requirements for the specific task. Work Permits require that management as well as the electricians sign-off that the job can be performed safely. Work Permits help prevent unnecessary risks and poor planning practices that lead to accidents.

Energized Work Permits should take into consideration: system operating conditions, the hazards involved, company work procedures and policies, safety requirements, etc. They should be logged electronically and backed-up to help ensure compliance and avoid liability due to lost documentation. EasyPower can do these tasks automatically as part of the Arc Flash Hazard Analysis (Refer to Section 4, Analyze).

8. SAFETY PROGRAM

Electrical safety is the heart of the NFPA 70E requirements and should be the goal of all companies and their employees. Defining safe work practices, procedures, and providing adequate documentation is essential in forming the basis for a safety program and developing a safety culture in your facility. Arc flash is one key aspect of a safety program that should also include practices and procedures for lock-out/tag-out, shock hazard, testing, tools, inspections, diagnostics, PPE, and a host of other safe work practices documented for reference. A proper electrical safety program will be centered on a company's Electrical Safe Work Practices Document.

9. TRAINING

All employees should receive training based on an Electrical Safe Work Practices Document every two years. Training should emphasize the major thought processes in working safely (i.e. training workers to evaluate each system/condition and making safe decisions). This is a key aspect in building a safe work culture that prepares workers to handle emergency situations. Additional types of training should also be considered for potentially hazardous day-to-day activities in your facility. These are site specific and may include: removing and installing MCC buckets, feeder bus duct plug-ins, or racking in breakers.

10. SYSTEM MAINTENANCE

System maintenance (including cleaning, breaker testing, insulation testing, etc.) is an integral part of electrical safety. Equipment maintenance and testing helps ensure that the equipment will be ready and operational to protect workers in the event of a hazard.

Electrical Safety Hazards

By Littelfuse

Safety in the workplace is job number one for employer and employee alike. It is especially important for those who install and service electrical systems. Nothing can replace a worker or loved one that has died or suffered the irreparable consequences of an electrical accident. No matter how much an employer tries to safeguard its workers or how much safety training is provided; the ultimate responsibility lies with the worker. The human factor is part of every accident or injury.

The purpose of this section is to identify electrical safety hazards and present ways to minimize or avoid their consequences. It is a guide for improving electrical safety and contains information about governmental regulations, industry-accepted standards and work practices. It presents ways to meet the standards and reduce the hazards.

While parts of the standards, regulations, and codes especially relating to electrical safety are quoted or summarized herein, it is the responsibility of the user to comply with all applicable standards in their entirety.

WHY IS ELECTRICAL SAFETY SO IMPORTANT?

Electrical hazards have always been recognized, yet serious injuries, deaths, and property damage occur daily. Organizations like the U.S. Department of Labor and the National Safety Council compile statistics and facts on a regular basis. The following table demonstrates the importance of electrical safety.

The moral obligation to protect workers who may be exposed to electrical hazards is fundamental, but there are legal and other factors that require every facility to establish a comprehensive Electrical Safety Program.

Meeting OSHA regulations, reducing insurance costs, and minimizing downtime and repair costs are additional benefits of Electrical Safety programs. When electrical faults occur, the electrical system is subjected to both thermal and magnetic forces. These forces can severely damage equipment and are accompanied by fires, explosions and severe arcing. Such violent damage often causes death or severe injury to personnel. Costs of repairs, equipment replacements, and medical treatment can run into millions of dollars. Loss of production and damaged goods are also important considerations.

Other major factors include the cost of OSHA fines and litigation. Severe electrical faults may shut down a complete process or assembly plant, sending hundreds or thousands of workers home for weeks while repairs are being made. It is also possible that one tragic event could close a plant permanently.

FACTS...

- 97% of all electricians have been shocked or injured on the job.
- Approximately 30,000 workers receive electrical shocks yearly.
- Over 3600 disabling electrical contact injuries occur annually.
- Electrocutions are the 4th leading cause of traumatic occupational fatalities.
- Over 2000 workers are sent to burn centers each year with severe Arc Flash burns.
- Estimates show that 10 Arc Flash incidents occur every day in the US.
- 60% of workplace accident deaths are caused by burn injuries.
- Over 1000 electrical workers die each year from workplace accidents.
- Medical costs per person can exceed $4 million for severe electrical burns.
- Total costs per electrical incident can exceed $15 million.
- In the year 2002, work injuries cost Americans $14.6 billion.

Implementing and following a well designed Electrical Safety Program will protect employees and employers against:

- Injury to personnel
- OSHA citations and fines
- Increased costs for insurance and workman compensation
- Lost or unusable materials
- Unplanned equipment repair or replacement costs
- Multi-million dollar lawsuits
- Possible bankruptcy

Electrical Safety is not an option — it is absolutely necessary for workers and employers alike.

ELECTRICITY BASICS

Even the simplest electrical system can become dangerous. Unless proper procedures are instituted, personnel installing or servicing these systems are frequently exposed to the hazards of shock, arc flash and arc blast. Eliminating and/or reducing these hazards require a basic knowledge of electric circuits. The following is a brief overview.

Electricity can be defined as the flow of electrons through a conductor. This is similar to the flow of water through a pipe. Electromotive force, measured in volts, causes the current to flow similar to a pump moving water. The higher the water pressure and the larger the pipes, the greater the water flow. In electrical circuits the rate of current flow is measured in amperes, similar to gallons of water per second. Figure 1 illustrates a simple circuit.

OHM'S LAW

In 1827, George Simon Ohm discovered that the flow of electric current was directly proportional to the applied voltage and inversely proportional to the "resistance" of the wires or cables (conductors) and the load. This discovery became known as Ohm's Law.

OHM'S LAW:

The Current in Amperes (I) is equal to the electromotive force, or Voltage (V) divided by the Resistance (R) in "ohms".

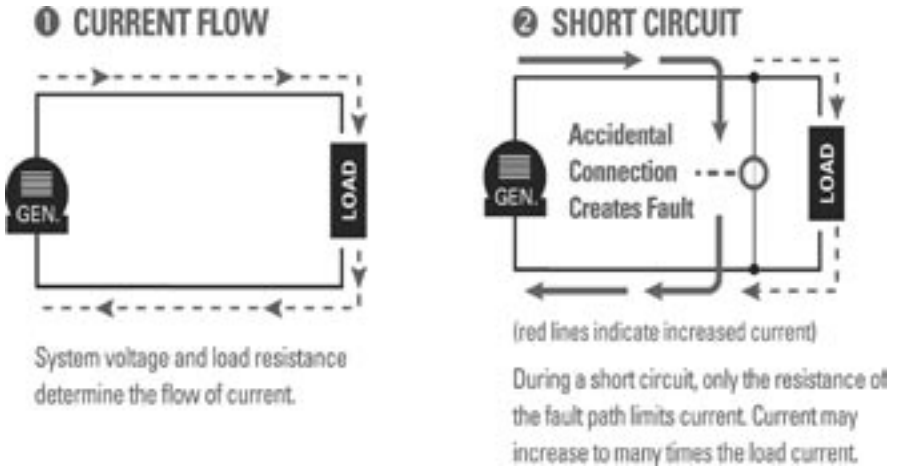

❶ CURRENT FLOW
GEN.
LOAD
System voltage and load resistance determine the flow of current.
❷ SHORT CIRCUIT
GEN.
Accidental Connection Creates Fault
LOAD
(red lines indicate increased current)
During a short circuit, only the resistance of the fault path limits current. Current may increase to many times the load current.

Figure 1

$$\text{Current (I)} = \frac{\text{Voltage (V)}}{\text{Resistance (R)}}$$

$$I = \frac{V}{R}$$

When two of the variables are known, the third can be easily determined using mathematical equations as shown above. Current seeks the path of least resistance; whether it is a conductor, the ground, or a human body. For example, at a given voltage, the higher the resistance is, the lower the current will be. The lower the resistance is, the higher the current will be. Materials that have very low resistance, such as metals like copper and aluminum, are termed conductors, while non-metallic materials like rubber, plastics, or ceramics that have very high resistance are termed insulators. Conductors are usually insulated to confine current to its intended path and to help prevent electrical shock and fires.

Conductor cross-section and material determine its resistance. Current produces heat as a function of current squared X resistance (I2R). The NEC publishes tables that show the rated current carrying capacity of various sizes and types of conductors (wire and cables). Currents that exceed the rating of the conductor increase temperature and decrease insulation life.

TYPES OF ELECTRICAL FAULTS

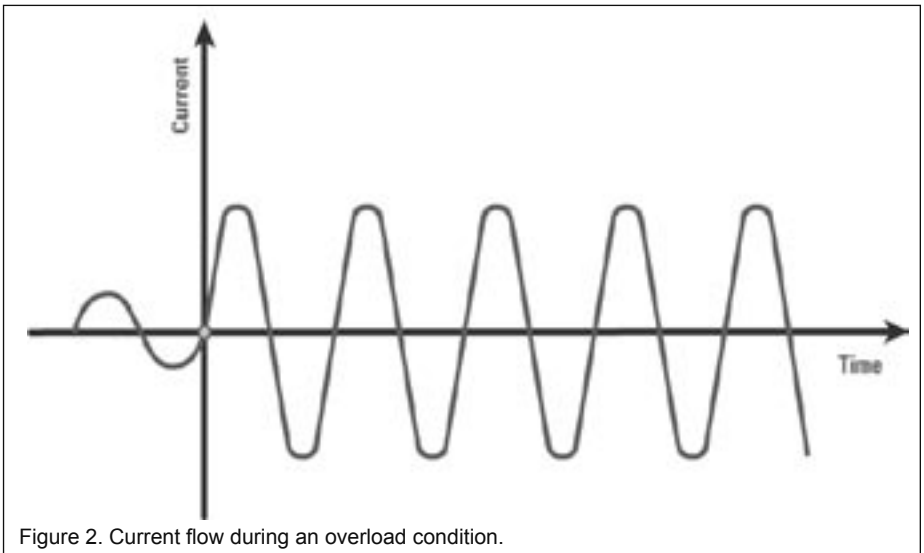


Figure 2. Current flow during an overload condition.

Together, current and voltage supply the power we use every day. Any electric current that exceeds the rating of the circuit is an overcurrent. When the current exceeds the rated current carrying capacity of the conductor, it generates excess heat that can damage insulation. If insulation becomes damaged, personnel may be severely injured and equipment or property compromised or destroyed. Overcurrents can be divided into two categories: overloads and short circuits.

An overload is defined as an overcurrent that is confined to the normal current path. Excessive connected loads, stalled motors, overloaded machine tools, etc. can overload a circuit. Most conductors can carry a moderate overload for a short duration without damage. In fact, transient moderate overloads are part of normal operation.

Startup or temporary surge currents for motors, pumps, or transformers are common examples.

Overcurrent protection must be selected that will carry these currents. However, if the overload persists for too long, excessive heat will be generated ultimately causing insulation failure.
This may result in fires or lead to a short circuit.

A Short Circuit is any current not confined to the normal path. The term comes from the fact that such currents bypass the normal load (i.e., it finds a "short" path around the load).

Usually, when a current is greater than 6 times (600%) the normal current, it should be removed as quickly as possible from the circuit. Short circuits are usually caused by accidental contact or worn insulation and are more serious than overloads. Damage occurs almost instantly.

Examples of short circuits include two or more conductors accidentally touching, someone touching or dropping tools across energized conductors or accidental connection between energized conductors and ground. Such ground faults may vary from a few amperes to the maximum available short circuit fault current.

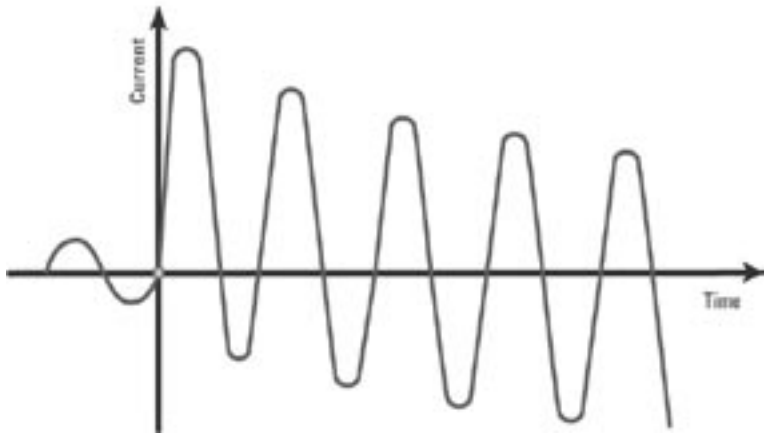


Figure 3. Current flow during a short circuit condition.

OVERCURRENT PROTECTIVE DEVICES

Overcurrent protective devices (fuses and circuit breakers) are used to protect circuits and equipment against overloads and short circuits (faults). These devices vary in characteristic, design and function. Fuses and circuit breakers are designed to sense abnormal overloads and short circuits and open the circuit before catastrophic events occur. Each device, however, has different time characteristics and must be used and applied according to the appropriate standards and manufacturer's recommendations for the individual application.

Fuses and circuit breakers must be able to discern the difference between normal current variations that pose no threat to equipment, and dangerous overloads or short circuits that can cause extensive damage to equipment and compromise safety. Not all devices are designed to protect against both overloads and short circuits. Most motor starters provide only overload protection, while some circuit breakers provide only short-circuit protection. Overcurrent protective devices should be selected carefully to make sure they will open the circuit safely under any abnormal overcurrent condition. Interrupting ratings and opening times, especially under short-circuit conditions, must also be carefully observed. Failure to select the properly rated overcurrent protective device can result in fires, explosions, and death.

INTERRUPTING RATING

Interrupting Rating (sometimes called Interrupting Capacity) is the highest available symmetrical rms alternating current (for DC fuses the highest DC current) at which the protective device has been tested, and which it has interrupted safely under standardized test conditions. Fuses and circuit breakers often have very different interrupting ratings. Current-limiting fuses have interrupting ratings up to 300,000 Amperes. UL Class H fuses and most common molded case circuit breakers have interrupting ratings of only 10,000 Amperes. If an overcurrent protective device with 10,000 AIR (Amperes Interrupting Rating) is used in a circuit that is capable of delivering a short circuit over 10,000 amperes, a vio-

lent explosion or flash fire can occur. Always use overcurrent protective devices that have interrupting ratings greater than the maximum available fault current of your electrical system.

CURRENT LIMITATIONS

What exactly is "Current Limitation" and why is it important? Article 240.2 of the National Electrical Code (NEC) defines a Current-Limiting Overcurrent Protective Device as: "A device that, when interrupting currents in its interrupting range, reduces the current flowing in the faulted circuit to a magnitude substantially less than that obtainable in the same circuit if the device were replaced with a solid conductor having comparable impedance." What this really means is that a current-limiting device is one that opens and clears a fault before the first current zero after the fault occurs, and limits the peak fault current. In most cases the current-limiting device will clear a fault in less than one half cycle of standard 60 Hz current (8.33 milliseconds).

Figure 4 is a graphical representation of the effect of current limitation on a faulted circuit.

As seen above, the total clearing time "t" occurs before the first zero. The I2t energy is the area under the curves. It is clear that I2t through the fuse is much less than would otherwise occur. Heating is a direct function of current squared x time (I2t). Reducing current in half reduces heat by 75%. Generally, the lower the peak instantaneous current is, the lower the I2t energy will be. The square of peak current determines the amount of magnetic stress.

For a given circuit, cutting the peak current in half reduces magnetic stress by 75%.

FUSES

A fuse is an intentional weak link in a circuit. It is a thermally responsive device designed to provide overcurrent protection.

The main function of a fuse is to protect conductors and equipment from damaging overcurrents and quickly de-energize faulted circuits, minimizing hazards to personnel.

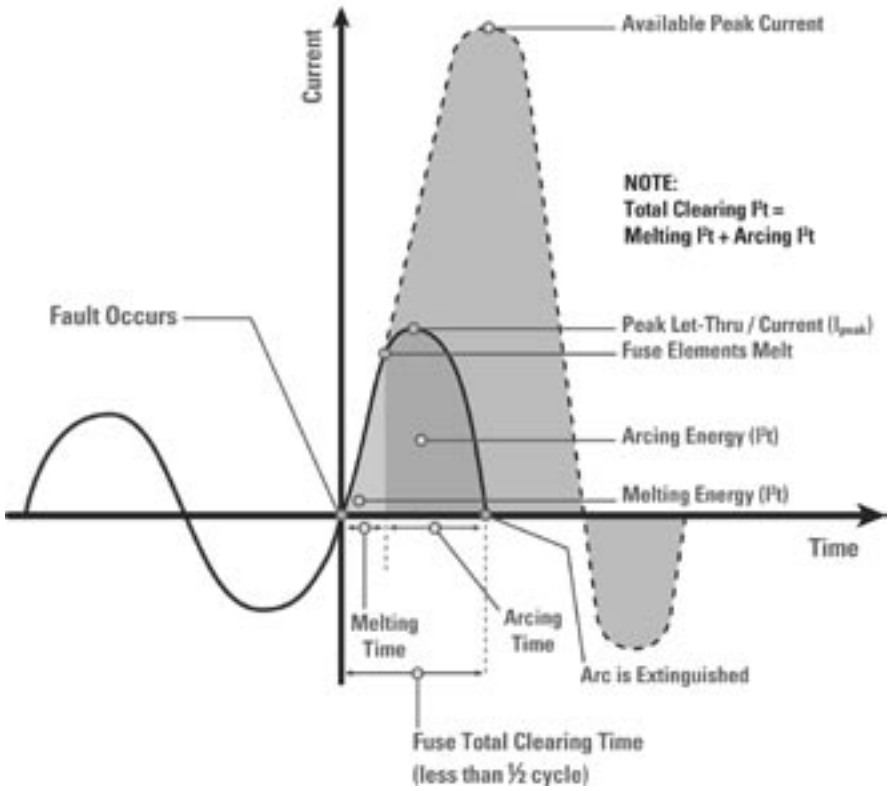


Figure 4.

Fuses may be classified as fast-acting or time-delay and as current-limiting or non-current-limiting.

Fast-acting fuses are designed to respond quickly to overload currents, while time-delay fuses are required to carry an overload current for a predetermined amount of time. This permits time-delay fuses to carry starting current and other temporary overloads. Fuses that limit the maximum peak current (Ip) that could flow during a short circuit are classified as current-limiting fuses. Whether the fuse is classified as fast-acting or time-delay, current-limiting fuses will open quickly during short-circuit conditions. Standard electrical fuses are available in current ratings from 1/10 to 6000 Amperes and for voltages up to 600 Volts. Underwriters Laboratories (UL) and CANENA (Council for the Harmonization of Electrotechnical Standards of the Americas) classify low-voltage fuses (600VAC and less) into several main classes such as R, J, CC, CD, L, T, G, H, K and Plug, as well as Semiconductor or Supplemental fuses. Each class is defined by its performance characteristics, size, and function. Low-voltage cartridge fuses are further classified as either current-limiting or non-current-limiting types. Cartridge fuses have ferrules, blades, or screw type methods of installation. They are generally intended for and suitable for branch circuit, feeder, and service entrance overcurrent protection in accordance with ANSI/NFPA 70, commonly known as the National Electrical Code.

Inside a typical fuse, the current flows through the fuse elements, or "links". When enough heat is generated, the fuse element will melt and open (blow). Most power fuses incorporate a silica sand "filler" material that safely quenches the

arc and stops the current flow.

Figure 5 illustrates the components of a Littelfuse LLSRK_ID current-limiting dual element time-delay fuse with blown fuse indication. It consists of two current sensing elements in series with each other. The first element is made with a very precise elastomeric silicone overload section that protects against sustained overloads. The second element opens quickly under short circuit conditions, limiting the damaging heat energy during short circuits and arc flash events. Finally, and perhaps just as important, the blown fuse indication makes troubleshooting and replacement safe, fast, and easy.

A fuse is designed to safely open the circuit only once. Therefore, it must be carefully selected to keep the equipment operating unless there is danger of severe overheating or if a short circuit or arcing fault occurs. Selecting the right fuse for the application is critical to overall safety and reliability. At the same time, fuses are fail-safe. Unlike mechanical devices, nothing can happen to a fuse that will prevent it from opening or increase its opening time.

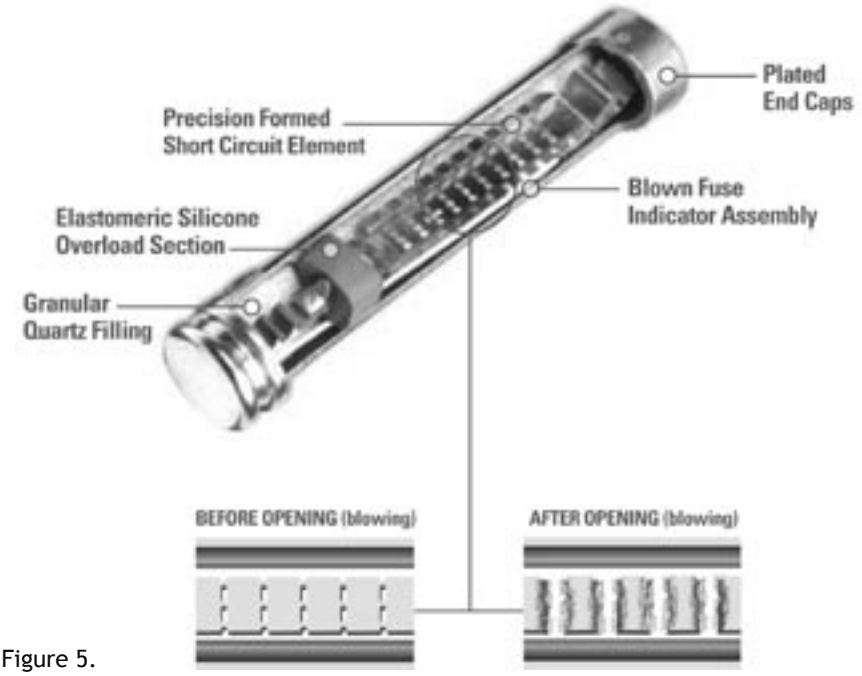


Figure 5.

CIRCUIT BREAKERS

Like fuses, circuit breakers are designed to protect circuits from overload and short circuit conditions when applied within their ratings.

Most circuit breakers utilize a mechanical latching, spring assisted switching mechanism and a thermal, thermal-magnetic, hydraulic-magnetic, or electronic current sensing circuit that causes the switching mechanism to unlatch and open the circuit. Typical circuit breakers are not current-limiting. However, current-limiting circuit breakers are available in some ratings, but at a higher cost.

Standard circuit breakers are available with current ratings up to 6300A and voltage ratings up to 1000V. As current levels increase, the type of circuit breaker may vary from Molded Case Circuit Breakers (MCCB) to Insulated-Case Circuit Breakers (ICCB) to Low-Voltage Power Circuit Breakers (LVPCB) types.

Some circuit breakers have magnetic only trip units or electronic trip sensors that can be adjusted for long, short, or instantaneous delays.

In all cases, the sensing circuit causes the switching circuit within the circuit breaker to operate (open). Due to the mass of the contacts and mechanical switching components and other factors, opening times of non-current limiting circuit breakers under short circuit conditions can vary from 3/4 cycles (13 msec.) to 8 cycles (130 msec.) or more.

Common Molded Case Circuit Breakers (MCCBs) such as the one shown in Figure 6 usually have "Thermal-Magnetic" trip units.

This means they have two sensing circuits in series with a spring assisted latching switch.

The first sensing circuit uses a "thermal" sensing element that reacts to overloads.

The second sensing circuit is a "magnetic" coil that reacts to short circuits. Either the thermal sensing circuit or the magnetic sensing circuit can cause the mechanically latched switching circuit to open the circuit. This provides time-current characteristics similar to dual-element fuses. However, most fuses have much higher interrupting ratings and react much faster to short circuits and arc flash events, making them safer and more reliable to use than most circuit breakers.

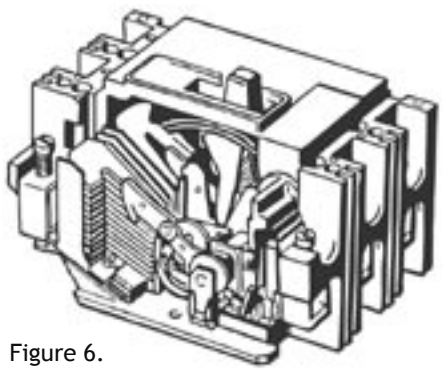


Figure 6.

Circuit breaker manufacturers typically recommend that their circuit breakers be cycled ON and OFF at least once each year to keep the tripping mechanism from seizing under certain environmental con-

ditions. Most manufacturers of industrial and commercial circuit breakers publish field-testing and maintenance instructions. This often includes annual testing and recalibration that requires special equipment and qualified personnel.

Instructions for thermal-magnetic breakers require many of these tests to be performed at room temperature that can take breakers out of service for several hours. After a circuit breaker has opened, it is very important to examine the circuit to determine if the cause was a short circuit or an overload. Article 225.3 of NFPA 70E requires that if a circuit breaker interrupts a fault at or near its interrupting rating, it must be inspected by a trained technician and tested, repaired or replaced in accordance with the manufacturer's specifications.

Circuit breakers must be carefully selected according to the application and NEC® requirements. Current ratings that are too low will cause nuisance tripping and excessive downtime. Current ratings that are too high can cause excessive overheating or higher arc flash hazards. Failure to follow NFPA standards and guidelines and the manufacturer's recommendations can result in catastrophic consequences.

Whether you use fuses or circuit breakers, both types of overcurrent protective devices must be tested and approved by a nationally recognized safety agency, such as Underwriters Laboratories. The device must also be applied in accordance with the National Electrical Code or other codes and standards required by the authority having jurisdiction over the facility. It is also important to remember that even if a fuse or circuit breaker is approved by a recognized safety agency like UL, it must be installed and used in accordance with any instructions included with its labeling or listing. There are differences, for example, in UL standards used to qualify fuses and circuit breakers such as UL 248, UL489, and UL1077. Always check the applicable standards and the manufacturer to determine if their devices meet the required interrupting ratings, voltage ratings, current limitation, etc. for each application. Failure to apply overcurrent protective devices within their ratings can result in fires, explosions, and deaths.

SHORT CIRCUIT CURRENT RATING (SCCR)

With all of the advances in engineering and safety, why is it that every day 1 maintenance person is either killed or injured in electricity related accidents? Is it possible the majority of effort that has gone into engineering and inspecting for safe electrical systems has ended when the electricity reaches the line side terminals of the equipment? The 2005 National Electrical Code addresses this situation with the advent of required labels on equipment that clearly state the equipment's Short Circuit Current Rating (SCCR). The NEC specifically addresses this for industrial control panels [Article 409], industrial machinery electrical panels [670], multiple motor HVAC equipment [440], meter disconnect switches [230] and multiple motor controllers [430].

The most dangerous and common misconception of SCCR by equipment manufacturers is that the interrupting capacity or rating of a circuit protection device is also the SCCR of the end use equipment in which it is installed. Meaning, the manufacturer that labels the equipment with a 22kA SCCR, solely because the main circuit breaker or fuse has an interrupting capacity of 22kA, is mislabeling its equipment and creating a potentially dangerous condition in your plant.

In order to build and label a safe piece of equipment, the manufacturer must determine the component in the primary electrical path with the lowest SCCR or withstand rating.

The SCCR of the equipment then must match the rating of that component with the lowest SCCR. Just as every device within the electrical distribution system of your facility must be rated to handle a worst-case scenario in order to completely protect the people and equipment within your facility, every component within your equipment must be designed to handle a worst-case scenario for exactly the same reason.

The NEC recognizes and specifically requires equipment to have accurate SCCR labels.

These labels will allow you and inspectors to compare fault current studies to the SCCR and minimize potential hazards in your facilities.

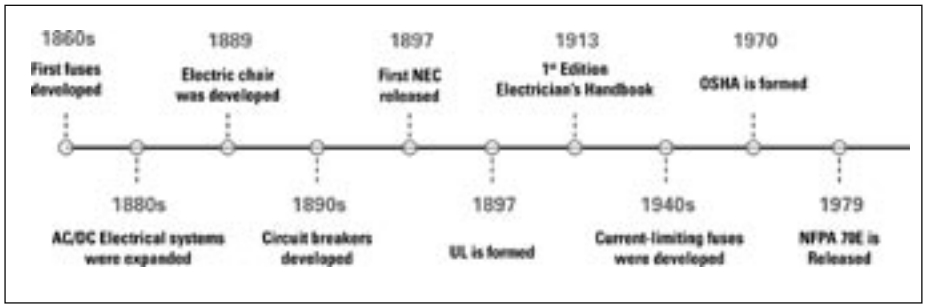
CIRCUIT PROTECTION CHECKLIST

Before a system is designed or when unexpected events may occur, circuit designers should ask themselves the following questions:

- What is the normal or average current expected?
- What is the maximum continuous (three hours or more) current expected?
- What inrush or temporary surge currents can be expected?
- Are the overcurrent protective devices able to distinguish between expected inrush and surge currents and open under sustained overloads and fault conditions?
- What kind of environmental extremes are possible? Dust, humidity, temperature extremes and other factors need to be considered.
- What is the maximum available fault current the protective device may have to interrupt?
- Is the overcurrent protective device rated for the system voltage?
- Will the overcurrent protective device provide the safest and most reliable protection for the specific equipment?
- Under short-circuit conditions, will the overcurrent protective device minimize the possibility of a fire or explosion?
- Does the overcurrent protective device meet all the applicable safety standards and installation requirements?

Answers to these questions and other criteria will help to determine the type of overcurrent protective device to use for optimum safety and reliability.

HISTORY OF ELECTRICAL SAFETY



Contrary to popular belief, Benjamin Franklin did not "discover" or "invent" electricity. The flow of electricity and its effects have been known for centuries, especially when traveling through air in the form of lightning. It wasn't until the late 18th and early 19th centuries, however, that scientists began to discover and analyze what electricity really is and how to harness it for man's benefit. Thus began the need to regulate electrical installations to protect people and equipment from its unintended effects.

With the advent of the electric light bulb and electric motors in the late 19th Century, it was soon discovered that electricity could also cause fires and kill people. Thomas Edison is said to have developed the first "fuse" by using a wire between two terminals that would melt if too much current flowed through it. In 1882, Edison opened the world's first central electric light power station in New York City. It produced enough DC current to power 7200 electric lamps. In 1887, Edison was issued the first fuse patent. Ever since, controlling electricity and protecting wires from fire has become more and more complex.

In an effort to increase electrical safety, Thomas Edison and George Westinghouse confronted each other on the relative benefits and dangers of Direct Current (DC) vs. Alternating Current (AC). Concerned with electrical safety, Thomas Edison tried to establish DC current as the standard in the U.S..

He argued that DC current was not as dangerous as AC, which George Westinghouse was promoting. In 1889, the state of New York commissioned the development of the electric chair for their capital punishment program. Even though Edison was not a proponent of capital punishment, he was asked to design the electric chair and assumed Westinghouse would be approached if he refused. Edison viewed this as an opportunity to prove that AC was more dangerous than DC and designed the "chair" using AC. In 1893, George Westinghouse received the contract to design the "Palace of Electricity" at the World's Columbian Exposition in Chicago. AC was used and shown to be safely applied. Obviously, Edison was proven wrong regarding the safe application of AC.

Westinghouse also had a better plan for generating and distributing electrical energy over long distances at higher voltages and then transforming it to lower useable voltages. Thus began the need for increased electrical construction and safety standards.

Because insurance companies were concerned about fire safety and electricity, the Underwriters Electrical Bureau (later to become UL) was established in 1894 to review various electrical safety standards and building codes that were quickly being developed. In the 1890s, the first crude circuit breakers were also developed. In 1896, the National Fire Protection Association was formed in New York City. Because electricity was viewed as a fire hazard, the National Board of Fire Underwriters unanimously approved the first "National Electrical Code" in June of 1897.

Thus, the "NEC" was born.

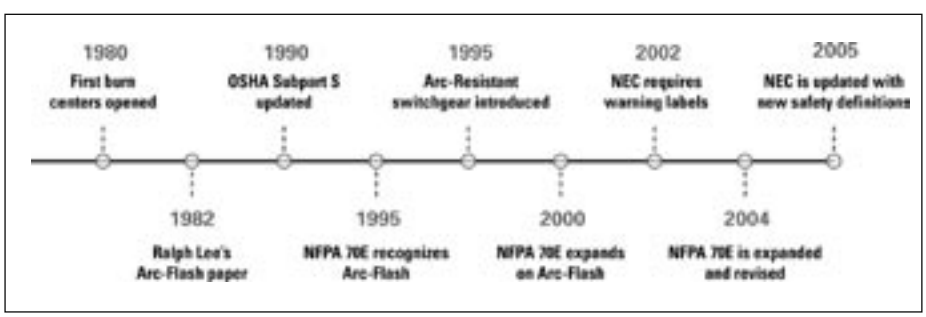
Many electric generating plants and transmission lines were built and installed in the US in the early 20th Century. Construction and safety standards were quickly developed. In 1904 Underwriters Laboratories published the first fuse standard. In 1913, the first edition of the "American Electricians' Handbook" was issued. In the 1930s, the Wiggington Voltage Tester (a.k.a. the "Wiggie") was developed for testing the presence of voltage, etc. In June of 1940, UL published the first circuit breaker standard, UL489, entitled "Branch-Circuit and Service Circuit-Breakers." It was later in the 1940s when the first current-limiting fuses were developed.

Despite advances in technology and as hard as it may be to believe, the American Electricians Handbook of 1942 had the following to say about Electrical Safety:

"Electricians often test for the presence of voltage by touching the conductors with the fingers.

This method is safe where the voltage does not exceed 250 and is often convenient to locating a blown-out fuse or for ascertaining whether or not a circuit is alive. Some men can endure the electric shock that results without discomfort whereas others cannot.

Therefore, the method is not feasible in some cases. Which are the outside wires and which is the neutral of a



115/230-volt, three-wire system can be determined in this way by noting the intensity of the shock that results by touching different pairs of wires with the fingers. Use the method with caution and be certain the voltage of the circuit does not exceed 250 before touching the conductors.

"The presence of low voltages can be determined by tasting. The method is feasible only where the pressure is but a few volts and hence is used only in bell and signal work. Where the voltage is very low, the bared ends of the conductors constituting the circuit are held a short distance apart on the tongue. If voltage is present a peculiar mildly burning sensation results, which will never be forgotten after one has experienced it. The taste is due to the electrolytic decomposition of the liquids on the tongue, which produces a salt having a taste. With voltages of 4 or 5 volts, due to as many cells of a battery, it is best to test for the presence of voltages by holding one of the bared conductors in the hand and touching the other to the tongue. Where a terminal of a battery is grounded, often a taste can be detected by standing on moist ground and touching a conductor from the other battery terminal to the tongue. Care should be exercised to prevent the two conductor ends from touching each other at the tongue, for if they do a spark can result that may burn."

After World War II, the demand for electric power increased for new construction and advances in productivity created the need for circuit protection devices with higher current ratings and interrupting capacities. Electrical safety standards and practices needed to keep pace with the ever-increasing growth of electrical power use and generation.

In 1970, when the Williams-Steiger Act was signed into law, the Occupational Safety and Health Administration (OSHA) was created. It took OSHA several years before they issued comprehensive regulations that governed aspects of all workers safety. At OSHA's request, the National Fire Protection Association, which issues the National Electrical Code, (NFPA 70), was asked to research and provide guidelines for electrical safety in the workplace. In 1979, the NFPA issued the first edition of NFPA 70E, entitled "Standard for Electrical Safety Requirements for Employee Workplaces" (since renamed the "Standard for Electrical Safety in the Workplace.") This was the first nationally accepted standard that addressed electrical safety requirements for employee workplaces.

In the 1970s, in addition to the known shock hazards associated with electricity, researchers began to address the phenomena of arcing faults that released large amounts of heat and light energy as well as pressure and sound energy. In 1980, Dr. Raphael Lee opened the first burn center in Chicago dedicated to the care and treatment of electrical burns.

In 1982, Mr. Ralph Lee (no relation) wrote an IEEE technical paper entitled "The Other Electrical Hazard: Electric Arc Blast Burns."

This paper introduced methods to determine and calculate the severity of electrical arc flash hazards. It remains today as one of the most comprehensive dissertations on the causes and effects of arc flash hazards. It was also the first notable publication that attempted to analyze and quantify the potential energy released during an arc flash event.

In 1990, OSHA updated subpart S of the Code of Federal Regulations, CFR 29 Section 1910, which deals specifically with the practical safeguarding of electrical workers at their workplaces. In 1995, NFPA 70E was revised to include formulas to establish shock and flash protection boundaries. Also in the mid 1990s, equipment makers began to design their equipment to be more arc resistant. In the year 2000, NFPA 70E was again revised to include an expanded section on arc flash hazards. In 2002, the National Electrical Code (NEC) was updated to include the requirement of shock and arc flash hazard warning labels on all equipment that is likely to be worked on while energized. Also in 2002, the IEEE (Institute of Electronic and Electrical Engineers) published IEEE 1584 "Guide for Performing Arc flash Hazard Calculation". The latest edition of NFPA 70E recognizes IEEE 1584 as a preferred method of calculating arc flash hazards.

In addition to OSHA, NFPA, and the IEEE, there are several other safety organizations and standards such as American National Standards Institute (ANSI), American Society of Testing and Materials (ASTM) and the International Electrotechincal Commission (IEC) that have developed practices and have set standards for materials and the testing of products to protect workers from electrical hazards.

ELECTRICAL SAFETY ORGANIZATIONS

Several organizations have developed and continue to revise standards to address the numerous concerns involving electrical power.

STANDARDS AND SAFETY ORGANIZATIONS INCLUDE:

- **OSHA**
Occupational Safety & Health Administration

- **NFPA**
National Fire Protection Association

- **IEEE**
Institute of Electrical and Electronic Engineers

- **UL**
Underwriters Laboratories

- **NEMA**
National Electrical Manufacturers Association

ANSI
American National Standards Institute

- **ASTM**
American Society for Testing and Materials

• NECA
National Electrical Contractors Association

OSHA

The primary goal of the Occupational Safety and Health Administration (OSHA) is "to ensure safe and healthful conditions for every American worker". OSHA currently has thousands of rules and regulations that cover workplace safety.

Federal and state OSHA programs enforce regulations through workplace inspections, voluntary assistance programs, and training activities. Citations and fines are also levied for violations found during inspections.

The General Duty Clause

Section 5(a)(1) of the Occupational Safety and Health Act of 1970 reads,

" 5. Duties
(a) Each Employer
(1) Shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees;"

The "General Duty Clause" is essentially the mission that OSHA strives to enforce. It is also often cited when OSHA investigates a workplace accident. Many OSHA regulations are prescriptive in nature like the "General Duty Clause". In other words, OSHA is the "shall" or the reason for addressing an issue. In some cases, OSHA will also provide detailed information on how to meet the requirements. In other instances, OSHA refers to national safety organizations such as NFPA to provide the required level of detail to meet the regulations. In either case, OSHA covers all employees and all employers.

OSHA Regulations

Published by the U.S. Federal Register, OSHA regulations can be found in the Code of Federal Regulations (CFR) under Title 29. More specifically, and legally enforced by OSHA, Subpart S (Parts 1910.301 to 1910.399) addresses "Electrical" safety standards and covers the practical safeguarding of electrical workers. Subpart S is divided into four major divisions:

- Design safety standards
- Safety-related work practices
- Safety-related maintenance requirements
- Safety requirements for special equipment

Other OSHA standards outline some of the general requirements for electrical installations and general safe work practices:

29 CFR 1910.132
Personal Protective Equipment General Requirements
29 CFR 1910.335
Electrical Personal Protective Clothing
29 CFR 1910.147
Control of Hazardous Energy (Lockout/Tagout)
29 CFR 1910.269
Power Generation, Transmission, & Distribution

OSHA and NFPA have worked with each other to establish standards and codes that ensure employee safety in the workplace. One of their objectives is to minimize the hazards of electricity through standards that specify safe design characteristics and work practices for electrical equipment and systems. Many of the standards and codes are not only accepted in the United States, but throughout the world.

NFPA

The primary organization in the U.S. for fire and electrical safety standards is the NFPA. Their document, NFPA 70E, Standard for Electrical Safety in the Workplace, has been adopted by the American National Standards Institute (ANSI) as an American National Standard. This standard covers safety related work practices, defines qualified and unqualified workers and provides guidance to establish an electrical safety program. It also requires an electrical hazard analysis for shock and flash, discusses energized work permits, and proper Lockout/tagout procedures. NFPA 70E defines and establishes shock and arc flash approach boundaries to energized equipment and addresses how to select appropriate PPE (personal protective equipment) and protective clothing.

In order to help meet the required OSHA regulations for electrical safety and training, OSHA refers to NFPA 70E as a national consensus standard for electrical safety in the workplace. NFPA also publishes NFPA 70, otherwise known as the National Electrical Code, and other standards that address public safety and practices. Together, OSHA and the NFPA continue to work to improve workplace safety. To ensure the safety of your plant and personnel, OSHA and NFPA standards should always be followed.

IEEE

The Institute of Electrical and Electronic Engineers, Inc. (IEEE) is an association of electrical and electronic engineers established to advance the theory and application of electro-technology and allied sciences. The Industry Application Society (IAS) of the IEEE is the group that addresses power distribution in industrial and similar facilities. There are numerous sub-committees that meet regularly to research, publish, and update standards and guidelines for the testing, evaluation, and application of their particular industry or specialty. In 2002, the Petroleum and Chemical Industry Committee IAS published IEEE1584, entitled, IEEE Guide for Performing Arc Flash Hazard Calculations. Although there are other methods of determining arc flash hazards, IEEE 1584 has quickly become the de facto standard for determining the extent of potential arc flash hazards.

NATIONALLY RECOGNIZED TESTING LABORATORIES (NRTL)

The best-known NRTL is Underwriters Laboratories, Inc. (UL). UL is an independent, not-for-profit product safety testing and certification organization that lists and labels products for conformance to accepted standards. Working with industry associations, manufacturers, experts, insurance companies, and government agencies, UL publishes various standards and minimum test requirements for all types of electrical equipment. Manufacturers submit their products to be evaluated for conformance to one or more of these standards. If the product meets or exceeds the standards, UL lists the product in their guides and permits manufacturers to display the UL label on the product. Protective devices such as fuses and circuit breakers must meet rigid standards such as UL248, UL489, or UL1077. There are other Nationally Recognized Testing Laboratories such as Canadian Standards Association (CSA), Electrical Testing Laboratories (ETL) that test and evaluate products to UL or other industry standards. Equipment that has been modified may require new evaluation and manufacturers routinely submit their products to UL for reevaluation to maintain their listing.

NEMA

The National Electrical Manufacturers Association (NEMA) has over 400 member companies including large, medium, and small businesses that manufacture products used in the generation, transmission and distribution, control, and end-use of electricity. NEMA has developed and published hundreds of standards jointly developed by its member companies.

The standards have been established in the best interests of the industry and users of its products. NEMA works closely with the American National Standards Institute (ANSI) and the International Electrotechnical Commission (IEC) to be an advocacy group to UL and governmental agencies. Many NEMA publications have been adopted by ANSI as American National Standards. Some address the use and application of overcurrent protective devices including AB3-2001 Molded Case Circuit Breakers and their Application; AB4-2003 Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications; and FU1-2002 Low-voltage Cartridge Fuses, while others address safety issues such as safety signs, tags, and barricades.

ANSI

The American National Standards Institute (ANSI) is a private, non-profit organization that administers and coordinates the U.S. voluntary standardization and conformity assessment system. Working in conjunction with organizations such as NFPA, IEEE, NEMA, ASME (American Society of Mechanical Engineers), ASCE (American Society of Civil Engineers), AIMME (American Institute of Mining and Metallurgical Engineers), and ASTM (American Society of Testing and Materials), ANSI coordinates and adopts these various industry consensus standards and publishes standards to promote U.S. and Global conformity. ANSI has adopted many NFPA, NEMA, and ASTM standards for procedures, materials, and personal protective equipment used by electrical workers.

ASTM

ASTM International, formerly known as the American Society for Testing and Materials, is a voluntary standards development organization primarily involved with establishing standards for the testing and analysis of materials.

The ASTM has published several standards accepted by ANSI and other organizations that govern the manufacturing, testing methods, and ratings of personal protective equipment used by electrical and other workers.

NECA

NECA, the National Electrical Contractors Association, is in the process of developing installation standards for electrical construction work. They have also developed electrical safety standards with emphasis on their members. In many cases, these standards are being adopted by ANSI.

ELECTRICAL SAFETY CODES AND STANDARDS

Over 20,000 standards have been developed to reduce the risk of electrical hazards. Except for OSHA regulations most standards do not automatically become law. However, they are often adopted by governmental bodies and become law; enforced by the Authority Having Jurisdiction (AHJ).

Other standards are written into manufacturing and construction specifications. Whether law or not, applicable standards should be followed to improve safety and reduce potential hazards.

WORKING ON DEENERGIZED EQUIPMENT

OSHA 29 Part 1910.333 covers selection and use of (electrical) work practices. It defines and regulates such things as working on or near energized or deenergized parts, Lockout/Tagout procedures, who is or is not considered qualified to work on live circuits, approach distances, use of personal protective equipment, and other requirements. Paragraph 1910.333 (a)(1) reads:

DE-ENERGIZED PARTS

Live parts to which an employee may be exposed shall be deenergized before the employee works on or near them, unless the employer can demonstrate that deenergizing introduces additional or increased hazards or is infeasible due to equipment design or operational limitations. Live parts that operate at less than 50 volts to ground need not be deenergized if there will be no increased exposure to electrical burns or to explosion due to electric arcs.

To demonstrate the close relationship between OSHA and NFPA 70E, here is what NFPA 70E Article 130.1 has to say regarding the need for equipment to be

de-energized:

Justification for Work

Live parts to which an employee might be exposed shall be put into an electrically safe work condition before an employee works on or near them, unless the employer can demonstrate that deenergizating introduces additional or increased hazards or is infeasible due to equipment design or operational limitations. Energized parts that operate at less than 50 volts to ground shall not be required to be deenergized if there will be no increased exposure to electrical burns or to explosion due to electric arcs...

When electrical equipment has been deenergized, OSHA Part 1910.147 (c) and 1910.333 (b)(2) requires lockout/tagout procedures be followed. Failure to follow lockout/tagout procedures is also consistently listed as one of the top ten OSHA violations.

HOW TO ESTABLISH AN ELECTRICALLY SAFE WORK CONDITION

Equipment that has been deenergized and verified as such is said to be in an electrically safe work condition. Article 120.1 of NFPA 70E outlines 6 steps that must be followed to insure that employees are working in an electrically safe work condition. They are:

1. "Determine all possible sources of electrical supply to the specific equipment. Check applicable up-to-date drawings, diagrams, and identification tags.

2. After properly interrupting the load current, open the disconnecting device(s) for each source.

3. Wherever possible, visually verify that all blades of the disconnecting devices are fully open or that drawout-type circuit breakers are withdrawn to the fully disconnected position.

4. Apply lockout/tagout devices in accordance with a documented and established policy.

5. Use an adequately rated voltage detector to test each phase conductor or circuit part to verify they are deenergized. Test each phase conductor or circuit part both phase-to-phase and phase-to-ground. Before and after each test, determine that the voltage detector is operating satisfactorily.

6. Where the possibility of induced voltages or stored electrical energy exists, ground the phase conductors or circuit parts before touching them. Where it could be reasonably anticipated that the conductors or circuit parts being deenergized could contact other exposed energized or circuit parts, apply ground connecting devices rated for the available fault duty.

It is important to note that a safe work condition does not exist until all 6 steps are complete. During the process of creating the electrically safe work condition, the appropriate PPE must also be utilized.

WORKING ON ENERGIZED EQUIPMENT

Although the best practice is to always work on deenergized equipment, OSHA and NFPA do recognize that in some circumstances it may create an additional hazard or be infeasible to deenergize. OSHA 29 CFR 1910.333 (a)(2) states:

ENERGIZED PARTS

If the exposed live parts are not deenergized (i.e., for reasons of increased or additional hazards or infeasibility), other safety-related work practices shall be used to protect employees who may be exposed to the electrical hazards involved. Such work practices shall protect employees against contact with energized circuit parts directly with any part of their body or indirectly through some other conductive object....

Electrical tasks such as troubleshooting and testing for the presence of voltage, current, etc., can only be done while equipment is energized. In these instances, work on energized equipment is allowed, but workers must follow safe work practices and use the appropriate PPE. Other exceptions that allow work on energized equipment include:

- Life-support equipment
- Emergency alarm systems
- Hazardous area ventilation equipment

De-energizing these types of equipment could increase or create additional hazards. A mistake often made is confusing infeasibility with inconvenience. For example, meeting a manufacturing production schedule does not qualify as infeasible. It may be very inconvenient but it still does not authorize working on energized equipment. OSHA 29 CFR 1910.331-335 outlines the conditions for working on energized circuits in much greater detail. When work is to be performed on energized equipment, extra care must be used and all applicable OSHA and NFPA codes and standards followed. Electrical workers must also be trained and specially "qualified" to work on energized equipment, and the specific equipment to be serviced.

Who is Qualified?

The definition of a "qualified" person continues to change and evolve. As a worker, you may be qualified for some tasks and unqualified for others. Knowing the difference may even save your life. It is no longer sufficient for those who will install and/or maintain electrical systems and equipment to be just "familiar" with the hazards involved. Training is the key in determining who is considered a qualified worker. All personnel who may be exposed to electrical hazards MUST receive documented training in order to become qualified. OSHA 29 CFR 1910.333 (c)(2) states:

"WORK ON ENERGIZED EQUIPMENT

Only qualified persons may work on electric circuit parts or equipment that have not been deenergized under the procedures of paragraph (b) of this section. Such persons shall be capable of working safely on energized circuits and shall be familiar with the proper use of special precautionary techniques, personal protective equipment, insulating and shielding materials, and insulated tools."

Article 100 of the National Electrical Code and NFPA 70E also defines a Qualified Person as:

"QUALIFIED PERSON

One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training on the hazards involved."

NFPA 70E Article 110.6 (D) Employee Training covers the requirements for "Qualified" persons in more detail. In addition to being trained and knowledgeable, qualified persons must also be familiar with emergency procedures, special precautionary techniques, personal protective equipment, arc flash, insulating materials and tools, and testing equipment. In some instances, employees receiving on-the-job training may be considered "qualified" for specific duties under supervision.

Ultimately, a person can be considered qualified with respect to certain equipment and methods but still be considered unqualified for others. Unqualified persons must also be trained in the risks they are exposed to and the procedures that are necessary to ensure their safety, however, they may not be considered "qualified" to work on specific equipment. It is vital that unqualified workers have an understanding of what tasks can only be performed by qualified workers.

CONDITION	EFFECTS
1-3mA of current	Mild sensation
10mA of current	Muscles contract, releasing grip may be difficult
30mA of current	Breathing difficult, possible loss of consciousness
30-75mA of current	Respiratory paralysis
100-200mA of current	Ventricular fibrillation
50-300mA of current	Shock (potentially fatal)
Over 1500mA of current	Tissue and organ burn
150° F	Cell destruction
200° F	Skin experiences "third degree" burns

Figure 7.

ENERGIZED ELECTRICAL WORK PERMIT

Before work is performed on energized equipment, NFPA 70E states:

Article 130 (A)(1)

" If live parts are not placed in an electrically safe work condition (i.e., for the reasons of increased or additional hazards or infeasibility per 130.1), work to be performed shall be considered energized electrical work and shall be performed by written permit only."

The intent of an Energized Electrical Work Permit is to discourage the practice of working on energized equipment. The objective is to get the supervisor or manager to recognize and fully understand the additional risks involved so they will be less likely to approve work on energized components. In essence, this shifts the decision to work on energized equipment from the worker to management.

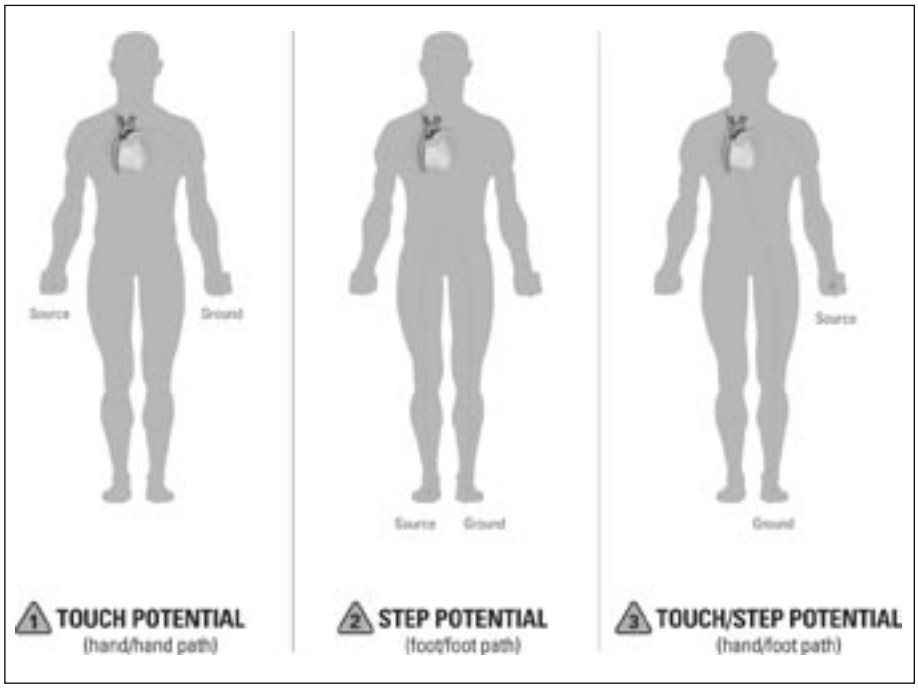
According to the NFPA 70E Handbook, work permits can also be written to cover a certain length of time for routine tasks provided the worker is trained and qualified. Other tasks that are not routine should generate a work permit as needed to insure the worker is trained and qualified for the task. Exceptions to the written work permit include testing, troubleshooting, and voltage measuring by qualified workers.

NFPA 70E does not require a specific format for an Energized Electrical Work Permit. However, it should contain the following 11 elements:

1. The location and description of equipment to be serviced
2. Justification why circuit cannot be deenergized
3. Description of safe work practices employed
4. Results of the shock hazard analysis
5. Determination of the shock protection boundaries
6. Results of the flash hazard analysis
7. The Flash Protection Boundary
8. Description of PPE to be used
9. Description of barriers used to restrict access
10. Evidence of job briefing
11. Signature of responsible management

The implementation and proper use of energized work permits has forced

employers and employees to perform hazard risk assessments and justify working on potentially hazardous energized equipment. At this time, OSHA does not specifically require the written Energized Electrical Work Permit. However, it is implied within current OSHA regulations and will most likely be enforced in future OSHA revisions. For an example of an Energized Electrical Work Permit refer to Annex C of this handbook or Annex J of NFPA 70E.



EMPLOYER AND EMPLOYEE RESPONSIBILITIES

According to OSHA and NFPA 70E, if work is planned or performed on energized equipment, employers must:

- Justify why work must be performed on energized equipment.
- Perform an electrical hazard assessment.
- Inform and train employees of the potential hazards and how to avoid them.
- Test and verify that employees are "qualified" to work on specific equipment.
- Select and provide proper personal protective equipment for employees.
- Train employees how to use and care for PPE.
- Provide their employees with a job briefing and written Energized Work Permit signed by management.

EMPLOYEES ARE EXPECTED TO:

- Be trained and "qualified"
- Use the PPE provided by their employer
- Inform their employers of the need to repair or replace PPE

At the end of the day, safety is the responsibility of both the employer and employee. Together they must develop and implement safe work practices and procedures and an Electrical Safety Program.

ARC FLASH AND OTHER ELECTRICAL HAZARDS

Electrical Safety Hazards

When electrical systems break down what are the primary hazards and what are the consequences to personnel?

- Electric shock
- Exposure to Arc flash
- Exposure to Arc-Blast
- Exposure to excessive light and sound energies

Secondary hazards may include burns, the release of toxic gases, molten metal, airborne debris and shrapnel. Unexpected events can cause startled workers to lose their balance and fall from ladders or jerk their muscles possibly causing whiplash or other injuries.

ELECTRIC SHOCK

When personnel come in contact with energized conductors they receive a shock with current flowing through their skin, muscles and vital organs. The severity of the shock depends on the current's path through the body, the current intensity, and the duration of the contact.

They may only experience a mild tingling sensation or it could result in serious injury or death. As voltage levels increase, the effects of electric shock escalate. Current may also cause an erratic heartbeat known as ventricular fibrillation. If fibrillation occurs even briefly and goes untreated, the effects are usually fatal.

A clear understanding of how electric current travels through the body can help minimize injury if such contact occurs. The table below outlines the effects that various values of electrical current have on the human body.

There are three basic pathways electric current travels through the body;

1) Touch Potential (hand/hand path)
2) Step Potential (foot/foot path)
3) Touch/Step Potential (hand/foot path)

Figure 8 illustrates these groups and the path of current through the body.

1) In a touch potential contact, current travels from one hand through the heart and out through the other hand. Because the heart and lungs are in the path of current, ventricular fibrillation, difficulty in breathing, unconsciousness, or death may occur.

2) In a step potential contact, current travels from one foot through the legs, and out of the other foot. The heart is

not in the direct path of current but the leg muscles may contract, causing the victim to collapse or be momentarily paralyzed.

3) In a touch/step potential contact, current travels from one hand, through the heart, down the leg, and out of the foot.

The heart and lungs are in the direct path of current so ventricular fibrillation, difficulty in breathing, collapse, unconsciousness, or death may occur.

Even though there may be no external signs from the electrical shock, internal tissue or organ damage may have occurred. Signs of internal damage may not surface immediately; and when it does, it may be too late. Any person experiencing any kind of electrical shock should seek immediate medical attention. Using the correct personal protective equipment (PPE) and following safe work practices will minimize risk of electrical shock hazards.

ARC FLASH AND ARC BLASTS

An arc flash is an unexpected sudden release of heat and light energy produced by electricity traveling through air, usually caused by accidental contact between live conductors.

Temperatures at the arc terminals can reach or exceed 35,000 degrees Fahrenheit (F), or four times the temperature of the sun's surface. The air and gases surrounding the arc are instantly heated and the conductors are vaporized causing a pressure wave called an Arc Blast.

Personnel directly exposed to an arc flash and arc blast events are subject to third degree burns, possible blindness, shock, blast effects and hearing loss. Even relatively small arcs can cause severe injury. The secondary effect of arcs includes toxic gases, airborne debris, and potential damage to electrical equipment, enclosures and raceways. The high temperatures of the arc and the molten and vaporized metals quickly ignite any flammable materials. While these fires may cause extensive property damage and loss of production, the hazards to personnel are even greater.

A Calorie is the amount of heat energy needed to raise the temperature of one gram of water by one degree Celsius.

ARC FLASH METRICS

Energy (E)	=	Power (P) × Time (t)
Power (P)	=	Volts (V) × Amps (I)
Calories (E)	=	Volts (V) × Amps (I) × Time (t)
1 Calorie	=	4.1868 watt-seconds
1 Joule	=	1 watt-second

Figure 8.

INCIDENT ENERGY (cal/cm²)	RESULTS/EXAMPLE
0.0033	Amount of energy the sun produces in 0.1sec. on the ground's surface at the equator.
1	Equivalent to a finger tip exposed to a cigarette lighter flame for one second
1.2	Amount of energy that will instantly cause 2nd degree burns to bare skin
4	Amount of energy that will instantly ignite a cotton shirt
8	Amount of energy that will instantly cause incurable 3rd degree burns to bare skin

Any energized electrical conductor that makes accidental contact with another conductor or with ground will produce an arc flash. The arcing current will continue to flow until the overcurrent protective device used upstream opens the circuit or until something else causes the current to stop flowing. The arc current can vary up to the maximum available bolted fault current.

ARC FLASH METRICS

In order to determine the potential effects of an arc flash, we need to understand some basic terms. An arc flash produces intense heat at the point of the arc. Heat energy is measured in units such as BTUs, joules, and calories. The following data provides a basis for measuring heat energy:

A Calorie is the amount of heat energy needed to raise the temperature of one gram of water by one degree Celsius.

Since energy equals power multiplied by time, and power (wattage) is volts X amps, we can see that calories are directly related to amperes, voltage, and time. The higher the current, voltage and time, the more calories produced.

To define the magnitude of an arc

flash and the associated hazards, some basic terms have been established: The amount of instantaneous heat energy released by an arc flash is generally called incident energy. It is usually expressed in calories per square centimeter (cal/cm^2) and defined as the heat energy impressed on an area measuring one square centimeter (cm^2).

However, some calculation methods express the heat energy in Joules/cm^2 and can be converted to calories/cm^2 by dividing by 4.1868.

If we place instruments that measure incident energy at varying distances from a controlled arc flash, we would learn that the amount of incident energy varies with the distance from the arc. It decreases approximately as the square of the distance in feet. Just like walking into a room with a fireplace, the closer we are, the greater the heat energy.

Tests have indicated that an incident energy of only 1.2 cal/cm^2 will cause a second-degree burn to unprotected skin. A second-degree burn can be defined as "just" curable.

For the purpose of understanding the potential effects of an arc flash, you must determine the working distance from an exposed "live" part. Most measurements or calculations are made at a working distance of 18 inches. This distance is used because it is the approximate distance a worker's face or upper body torso may be away from an arc, should one occur.

Some parts of a worker may be less than 18 inches away, but other work may be performed at greater distances. The working distance is used to determine the degree of risk and the type of personal protection equipment necessary to protect against the hazard.

NFPA 70E, Standard for Electrical Safety in the Workplace categorizes Arc flash Hazards into five Hazard Risk Categories (HRC 0 through 4) based on the amount of energy that can be released at a certain working distance during an arc flash event. They are:

Studies show that many industrial arc flash events produce 8 cal/cm^2 (HRC 2) or less, but other accidents can produce 100 cal/cm^2 or more (exceeding all HRC). It is important to remember that it only takes 1.2 cal/cm^2 (HRC 0) to cause a second degree burn to unprotected skin.

INCIDENT ENERGY (cal/cm^2)	HAZARD RISK CATEGORY
0 to 1.2	0
1.21 to 4	1
4 .1 to 8	2
8.1 to 25	3
25.1 to 40	4

OVERCURRENT PROTECTIVE DEVICE	TYP. OPENING TIME AT 8 × RATING	TYPICAL OPENING TIME AT 20 × RATING
Current-limiting fuses or current-limiting circuit breakers	0.1 to 1 second	< ½ cycle = 8.3 milliseconds
Molded case circuit breakers without adj. trip	5 to 8 seconds	1.5 cycles = 25 milliseconds
Molded case circuit breakers with adj. trip	1 to 20 seconds	1.5 cycles = 25 milliseconds
Large air power breakers with electronic trip	5 to 20 seconds	3 cycles = 50 milliseconds
Medium voltage breakers with electronic trip	5 to 20 seconds	5 to 6 cycles = 100 milliseconds

WHAT DETERMINES THE SEVERITY OF AN ARC FLASH?

Several groups and organizations have developed formulas to determine the incident energy available at various working distances from an arc flash. In all cases, the severity of the arc flash depends on one or more of the following criteria:

- Available short circuit current
- System voltage
- Arc gap
- Distance from the arc
- Opening time of overcurrent protective device (OCPD)

When a severe enough arc flash occurs, the overcurrent protective device (fuse or circuit breaker) upstream of the fault interrupts the current. The amount of incident energy a worker may be exposed to during an arc flash is directly proportional to the total clearing ampere-squared seconds (I2t) of the overcurrent protective device during the fault. High current and longer exposure time produces greater incident energy.

The only variable that can be positively and effectively controlled is the time it takes for the overcurrent protective device to extinguish the arc. A practical and significant way to reduce the duration of an arc flash and thereby the incident energy is to use the most current-limiting OCPDs throughout the electrical system.

Current-limiting devices such as Littelfuse type LLSRK_ID or JTD_ID fuses will

open in 1/2 AC cycle (8.33 milliseconds) or less under short circuit conditions. Studies have shown that many existing molded case circuit breakers take up to 6 AC cycles (100 milliseconds) or longer to open under short circuit conditions. Refer to the "Overcurrent Protective Device" table showing the typical opening times for various overcurrent protective devices.

ARC BLAST EFFECT

During an arc flash, the rapidly expanding gases and heated air may cause blasts, pressure waves, or explosions rivaling that of TNT.

The gases expelled from the blast also carry the products of the arc with them including droplets of molten metal similar to buckshot. For example, the high temperatures will vaporize copper, which expands at the rate of 67,000 times its mass when it changes from solid to vapor. Even large objects such as switchboard doors, bus bars, or other components can be propelled several feet at extremely high velocities. In some cases, bus bars have been expelled from switchboard enclosures entirely through walls. Blast pressures may exceed 2,000 pounds per square foot, knocking workers off ladders or collapsing workers' lungs. These events occur very rapidly with speeds exceeding 700 miles per hour making it impossible for a worker to get out of the way.

Light and Sound Effects

The intense light generated by the arc flash emits dangerous ultraviolet frequencies, which may cause temporary or permanent blindness unless proper protection is provided. The sound energy from blasts and pressure waves can reach 160 dB, exceeding the sound of an airplane taking off, easily rupturing eardrums and causing permanent hearing loss. For comparison, OSHA states that decibel levels exceeding 85 dB require hearing protection.

Common Causes

The most common cause of arc flash and other electrical accidents is carelessness. No matter how well a person may be trained, distractions, weariness, pressure to restore power, or overconfidence can cause an electrical worker to bypass safety procedures, work unprotected, drop a tool or make contact between energized conductors. Faulty electrical equipment can also produce a hazard while being operated.

Electrical safety hazards such as exposure to shock and arc flash can also be caused by:

- Worn or broken conductor insulation
- Exposed live parts
- Loose wire connections
- Improperly maintained switches and circuit breakers
- Obstructed disconnect panels
- Water or liquid near electrical equipment
- High-voltage cables
- Static electricity
- Damaged tools and equipment

The severity and causes of electrical hazards are varied, but the best protection is to deenergize equipment before working on it. No one has ever been killed or injured from an arc flash while working on deenergized equipment. If equipment cannot be de-energized, electrical workers must be "qualified",

trained, wear appropriate personal protective equipment (PPE), and follow all applicable OSHA and NFPA standards. It is important to remember that proper selection and application of overcurrent protective devices (OCPD) will also substantially reduce the hazards.

ELECTRICAL HAZARD ANALYSIS

Both OSHA and NFPA 70E require an Electrical Hazard Analysis prior to beginning work on or near electrical conductors that are or may become energized. The analysis must include all electrical hazards: shock, arc flash, arc blast, and burns. NFPA 70E Article 110.8(B)(1) specifically requires electrical hazard analysis within all areas of the electrical system that operate at 50 volts or greater. The results of the electrical hazard analysis will determine the work practices, protection boundaries, personal protective equipment, and other procedures required to protect employees from arc flash or contact with energized conductors.

SHOCK HAZARD ANALYSIS

NFPA 70E Articles 110.8(B)(1) and 130.2(A) require a shock hazard analysis. The shock hazard analysis determines the system voltage to which personnel can be exposed, the protection boundary requirements as established in NFPA 70E Table 130.2(C), and identifies personal protective equipment (PPE) required to minimize shock hazards.

APPROACH BOUNDARIES

NFPA 70E has established three shock protection boundaries:

1) Limited Approach Boundary
2) Restricted Approach Boundary
3) Prohibited Approach Boundary

LIMITED APPROACH BOUNDARY

The limited approach boundary is an approach boundary to protect personnel from shock. A boundary distance is established from an energized part based on system voltage. To enter this boundary, unqualified persons must be accompanied by a qualified person and use PPE.

Table A

$D_c = [2.65 \times MVA_{bf} \times t]^{1/2}$ OR $D_c = [53 \times MVA \times t]^{1/2}$

D_c	= FPB distance in ft. from the Arc
MVA_{bf}	= Available bolted fault MVA in mega volt-amps at point of fault
MVA	= Transformer capacity in mega volt-amps
t	= Clearing time of overcurrent protective device in seconds

Table B

$E_{MB} = 1038.7\, D_B^{-1.4738}\, t_A\, [0.0093F^2 - 0.3453F + 5.9675]$ cal/cm^2

E_{MB}	= Maximum 20 in. cubic box incident energy
D_B	= Distance from arc electrodes, (usually 18 in.)
t_A	= Arc duration, seconds
F	= Bolted fault current in kA

Note: The formula in Table B only applies to systems where the available short circuit current is in the range of 16kA to 50kA.

Figure 9. Shock Protection Boundaries

RESTRICTED APPROACH BOUNDARY

The restricted approach boundary is an approach boundary to protect personnel from shock. A boundary distance is established from an energized part based on system voltage. Only qualified persons are allowed in this boundary and they must use PPE.

PROHIBITED APPROACH BOUNDARY

The prohibited approach boundary is an approach boundary to protect personnel from shock. Work in this boundary is considered the same as making direct contact with an energized part. Only qualified persons are allowed to enter this boundary and they must use PPE.

Shock protection boundaries are based on system voltage and whether the exposed energized components are fixed or movable.

NFPA 70E Table 130.2(C) defines these boundary distances for nominal phase-to-phase system voltages from 50 Volts to 800kV.

Approach boundary distances may range from an inch to several feet. Please refer to NFPA 70E Table 130.2(C) for more information.

In summary, a shock hazard analysis is performed to reduce the potential for direct shock. It will establish shock protection boundaries and determine PPE required for protecting workers against shock hazards.

FLASH HAZARD ANALYSIS

A complete electrical hazard analysis must also contain a flash hazard analysis. NFPA 70E Article 130.3 requires this analysis to be performed:

"A flash hazard analysis shall be done in order to protect personnel from the possibility of being injured by an arc flash. The analysis shall determine the flash protection boundary and the personal protective equipment that people within the flash protection boundary shall use."

The analysis requires the available fault current to be calculated and documented at every point in the electrical system. This includes all components contained in the electrical system.

The end result of this research will be an accurate, documented one-line diagram which will provide the data for a short circuit analysis, and the other

calculations that determine the flash protection boundary and required level of PPE. In part, arc flash hazard calculations are based on the available fault current and the opening time of overcurrent protective devices. NFPA 70E has also assigned hazard risk categories based on the estimated incident energy (typically expressed in cal/cm2), from an arc flash.

The Flash Protection Boundary (FPB)

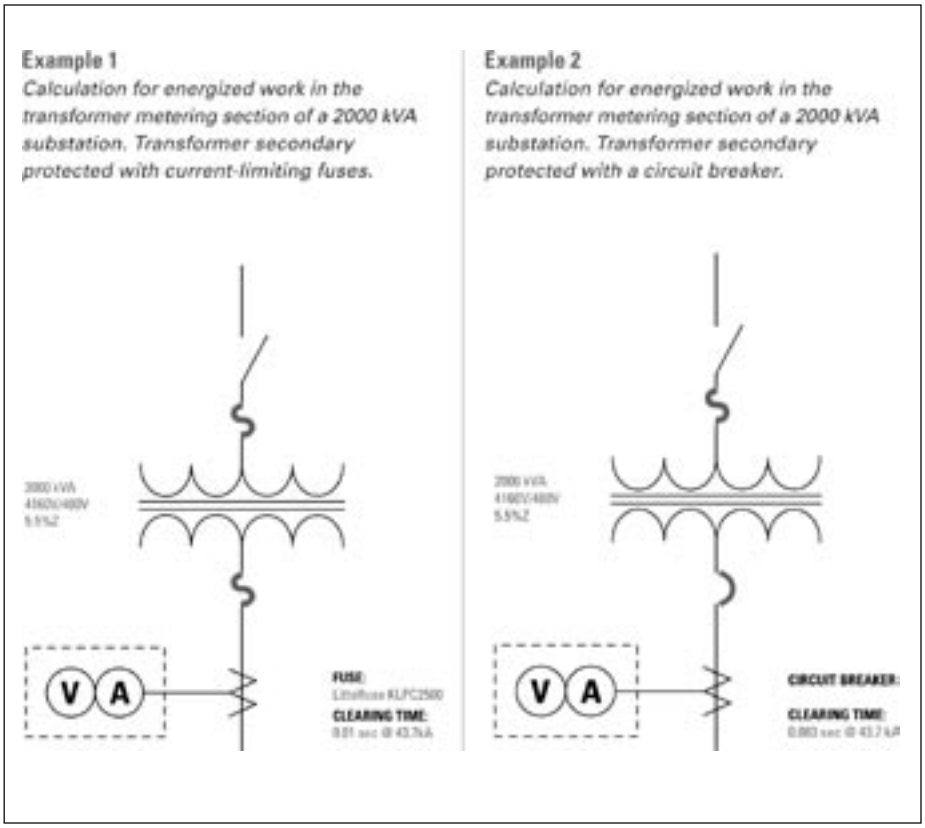
The flash protection boundary is the distance in feet (DC) from a given arc source that will produce a second-degree burn on exposed bare skin.

Unlike the shock hazard protection boundaries that are based solely on system voltage, the flash protection boundary is not fixed. In order to determine the potential arc flash hazard, flash protection boundaries must be calculated at every point where service on energized equipment, devices, or conductors may be required. The discussion and examples that follow are intended to introduce readers to the required data and some of the methods for performing an electrical flash hazard analysis at 600 volts and below. Readers are cautioned that calculations for systems with different voltages, equipment, devices, and a wider range of fault currents require the more complete methods contained in NFPA 70E Article 130 and Annex D.

According to NFPA 70E, the default flash protection boundary is four feet (48”) based on an OCPD clearing time of 6 cycles (0.1 sec) and an available fault current of 50 kA or other combinations not exceeding 5,000-ampere seconds. For other conditions or under engineering supervision, calculations are permitted to determine the Flash Protection Boundary. Complete formulas for varying conditions are given in NFPA 70E Article 130 and NFPA 70E Annex D.

The following data is required to complete the flash hazards analysis:

• Up-to-date one-line circuit diagram of the electrical distribution system


Example 1
Calculation for energized work in the transformer metering section of a 2000 kVA substation. Transformer secondary protected with current-limiting fuses.
V
A
FUSE
CLEARING TIME
Example 2
Calculation for energized work in the transformer metering section of a 2000 kVA substation. Transformer secondary protected with a circuit breaker.
V
A
CIRCUIT BREAKER
CLEARING TIME

• Available fault current from the utility or generator

• Maximum available bolted fault currents at each location

• Minimum self-sustaining arcing current at each location

• Clearing times of all overcurrent protective devices

As power is distributed throughout your facility, it is important to remember that although voltage levels may be higher at the service entrance, secondary power distribution transformers can produce much higher current levels and arc flash energy levels. Power utilities should be consulted regularly to establish the maximum available fault current at the service entrance location of your building. Hand calculations or commercial software can be used to estimate the maximum available short circuit current at every access point in your electrical system.

Arc Flash Calculations

If the maximum available fault current at a particular location is known, then an analysis of the upstream overcurrent protective device (OCPD) will determine how fast the device will clear the circuit at the fault current. If these two factors are known, the amount of incident energy and the flash protection boundary can be calculated.

The flash protection boundary (Dc) measured in feet is based on the bolted fault mega voltamperes (MVAbf) and the clearing time (t) of the OCPD. If the bolted fault current (Isc) is not known, it can be calculated based on the MVA rating and impedance of the source transformer.

An alternate method of determining the flash protection boundary based on the MVA rating of a source transformer with an impedance of 5% and the clearing time (t) of the OCPD is supplied in NFPA 70E.

Table A provides a basic formula for calculating the flash protection boundary.

Example 1 (continued)

NFPA 70E Article 130.3 (A)
Flash Protection Boundary Distance

Calculate MVA_{bf}:

Note: 2000 kVA = 2 MVA

$$MVA_{bf} = \frac{100}{\%Z} \times MVA = \frac{100}{5.5} \times 2$$

MVA_{bf} = 36.4 MVA

Calculate D_C:

t = 0.01 sec

$$D_C = \sqrt{(2.65 \times MVA_{bf} \times t)}$$

$D_C = \sqrt{(2.65 \times 36.4 \times 0.01)}$ = 0.98 ft ≅ 12 inches

NFPA 70E Annex D.6.2(a)
Incident Energy Exposure

Calculate I_{bf}:

$$I_{bf} = \frac{MVA \times 10^6}{\sqrt{3} \times V_{bf}} \times \frac{100}{\%Z}$$

$$I_{bf} = \frac{2 \times 10^6}{\sqrt{3} \times 480} \times \frac{100}{5.5} = 43{,}738 \text{ Amps}$$

Calculate F:

$$F = \frac{I_{bf}}{1000} = \frac{43{,}738 \text{ A}}{1000} = 43.7 \text{ kA}$$

Calculate E_{MB}:

For this calculation, D_b = 18 inches

$E_{MB} = 1038.7 \times D_b^{-1.4738} \times t_a \times (0.0093 F^2 - 0.3453 F + 5.9675)$

$E_{MB} = 1038.7 \times (18)^{-1.4738} \times (.01) \times [0.0093 (43.7)^2 - 0.3453 (43.7) + 5.9675]$

E_{MB} = 1.27 cal/cm²

Example 2 (continued)

NFPA 70E Article 130.3 (A)
Flash Protection Boundary Distance

Calculate MVA_{bf}:

Note: 2000 kVA = 2 MVA

$$MVA_{bf} = \frac{100}{\%Z} \times MVA = \frac{100}{5.5} \times 2$$

MVA_{bf} = 36.4 MVA

Calculate D_C:

t = 0.083 sec

$$D_C = \sqrt{(2.65 \times MVA_{bf} \times t)}$$

$D_C = \sqrt{(2.65 \times 36.4 \times 0.083)}$ = 2.83 ft ≅ 34 inches

NFPA 70E Annex D.6.2(a)
Incident Energy Exposure

Calculate I_{bf}:

$$I_{bf} = \frac{MVA \times 10^6}{\sqrt{3} \times V_{bf}} \times \frac{100}{\%Z}$$

$$I_{bf} = \frac{2 \times 10^6}{\sqrt{3} \times 480} \times \frac{100}{5.5} = 43{,}738 \text{ Amps}$$

Calculate F:

$$F = \frac{I_{bf}}{1000} = \frac{43{,}738 \text{ A}}{1000} = 43.7 \text{ kA}$$

Calculate E_{MB}:

For this calculation, D_b = 18 inches

$E_{MB} = 1038.7 \times D_b^{-1.4738} \times t_a \times (0.0093 F^2 - 0.3453 F + 5.9675)$

$E_{MB} = 1038.7 \times (18)^{-1.4738} \times (.083) \times [0.0093 (43.7)^2 - 0.3453 (43.7) + 5.9675]$

E_{MB} = 10.54 cal/cm²

DATA	EX. 1 - FUSE	EX. 2 - CIRCUIT BREAKER
Fault Current (I_{SC})	43.7 kA	43.7 kA
Flash Protection Boundary (D_C)	12 inches	34 inches
Incident Energy (E_{MB})	1.27 cal/cm²	10.54 cal/cm²
Hazard Risk Category	1	3

Multiple methods are also provided in NFPA 70E Annex D for estimating incident energy under varying conditions. The results can vary drastically depending on the specific system parameters. An arcing fault will also produce very different incident energy levels depending on if the arc is in open air or confined in a cubic box.

The formula in Table B estimates the incident energy for a fault occurring in a 20 inch cubic box with one side open. This estimate simulates the potential effect of an arc flash while working in equipment and switchgear enclosures.

During arcing faults, the arc impedance (resistance) reduces arc current. Because the opening times of OCPD increase as the short-circuit current (Isc) decreases, lower arc fault currents may greatly increase the total arc energy. Studies have shown that the minimum self-sustainable arc in 480 volt systems is 38% of the available bolted fault current. Because of the increased time at this reduced fault level, the incident energy may be higher than under bolted fault conditions. Each point in the system needs to be evaluated for both maximum and minimum fault currents.

ARC FLASH HAZARD CALCULATION EXAMPLES

The following examples break down the calculations and compare the hazard risk category (HRC), incident energy (cal/cm2), flash protection boundary (FPB) and PPE (personal protective equipment) required to work on an energized 480V system protected by either 2500 Amp Class L fuses or a 2500 Amp low voltage power circuit breaker.

EXAMPLE RESULTS COMPARISON

As the examples show, the flash protection boundary, incident energy, and hazard risk category can vary greatly depending on the overcurrent protective device being used. In this particular comparison, the required level of PPE would also be quite different between the fuse and circuit breaker. The above calculations can also be performed using commercially

available software programs. Refer to Annex D of this handbook for more details on the steps required to complete the hand calculations.

IEEE 1584 ARC FLASH HAZARD CALCULATION

The Institute of Electrical and Electronic Engineers (IEEE) publishes the IEEE 1584 "Guide for Performing Arc Flash Hazard Calculations". It contains detailed methods and data that can be used to calculate arc flash hazards for the simplest to the most complex systems. The Petroleum and Chemical Industry committee of the IEEE spent many years developing these methods. They are based on empirical testing of Class RK1 and Class L fuses, Low Voltage Molded Case Circuit Breakers, Insulated Case Circuit Breakers and Low Voltage Power Circuit Breakers as well as theoretical modeling. Included in 1584 are spreadsheet programs that simplify the calculation of incident energy and flash-protection boundaries.

IEEE 1584 does not address the Safety-related Work Pratices in the same manner as NFPA 70E. IEEE 1584 concerns itself primarily with performing the calculations that may be necessary to determine safe practices.

The calculation methods in Annex D of NFPA 70E are based on IEEE 1584 but do not contain all the data or descriptions of how these methods were developed. IEEE 1584 outlines 9 steps necessary to properly perform an arc flash hazard calculation.

STEP 1 - COLLECT THE SYSTEM AND INSTALLATION DATA

Depending on whether you are doing a complete site analysis or looking at one individual portion, this step can take a few minutes or several weeks to perform. Begin by reviewing the latest up-to-date single line diagram(s) of the equipment or system you are analyzing. If single line diagrams are not available, you must create them. The utility can provide you with the available fault MVA and X/R ratio at the entrance to your facility.

If you generate your own electricity, or if you have emergency or standby generators and large motors, a more detailed analysis must be performed. In order to calculate the bolted fault current available at the point of your application, you must record on your one-line diagram all transformers and their ratings, circuit breakers or fusible distribution circuits and their ratings, MCCs, and all other equipment between the power source and the area you are concerned with. Next, you must record the size, type, length, and number of cables or busbars, etc. used between the utility and the distribution and control equipment being analyzed. The type of conduit or raceway must also be recorded. All transformer data must be recorded including MVA ratings and impedance, and all overcurrent protective devices must be identified with their specific characteristics or trip ratings recorded.

STEP 2 - DETERMINE THE SYSTEM MODES OF OPERATION

Most installations have only one mode of operation with one utility connection. However, larger industrial or commercial buildings or manufacturing plants may have two or more utility feeders with tie switching of two or more transformers, or co-generators running in parallel. Each mode can be very complex and require a detailed hazard analysis.

STEP 3 - DETERMINE THE BOLTED FAULT CURRENTS

You can perform hand calculations or use commercially available software programs such as the Littelfuse EDR software to calculate the bolted fault currents at all points between the utility and the distribution or control equipment you are analyzing. It will be necessary to plug in all of the data you have recorded about the transformers, cable sizes and lengths, and type of conduit, etc. used in each installation to determine the bolted fault currents.

STEP 4 - DETERMINE THE ARC FAULT CURRENTS

After determining the bolted fault currents, IEEE 1584 provides a formula to calculate the predicted arc fault current due to typical arc impedance and other factors. The predicted arc fault current for system voltages under 1kV depends on the bolted fault current, system voltage, arc gap, and whether the arc would most likely occur in the open air or in an enclosed box configuration.

STEP 5 - FIND THE PROTECTIVE DEVICE CHARACTERISTICS AND THE DURATION OF THE ARCS

From the data collected in Step 1 and the predicted arc fault current determined in Step 4, the next step is to establish the total clearing time of the overcurrent protective device immediately on the LINE side of the equipment you are analyzing. If the fuse manufacturer or circuit breaker manufacturer publishes maximum and minimum clearing times, it is important to use the maximum clearing time possible for the predicted arc fault current.

NOTE: This step can be omitted if the overcurrent protective devices are those already tested and listed in the IEEE 1584 document. See Section 4.6 of IEEE 1584.

STEP 6 - DOCUMENT THE SYSTEM VOLTAGES AND CLASSES OF EQUIPMENT

Make sure you document the system voltages and class of equipment such as 15kV switchgear, 5kV switchgear, low-voltage switchgear, low-voltage MCCs and panelboards, or cable runs.

STEP 7 - SELECT THE WORKING DISTANCES

IEEE 1584 has established three typical working distances for different classes of equipment. As previously discussed, incident energy calculations and hazard risk categories will depend on the working distances selected.

STEP 8 - DETERMINE THE INCIDENT ENERGY FOR ALL EQUIPMENT

You can use formulas included in the

IEEE 1584 document or commercially available software to calculate the incident energy possible in cal/cm2 at the working distance selected.

STEP 9 - DETERMINE THE FLASH PROTECTION BOUNDARY FOR ALL EQUIPMENT

The formulas given within IEEE 1584 can be used to determine the distance from the arc at which the onset of a second-degree burn will occur to unprotected skin. This distance must be established and will vary based on system parameters.

Software programs automatically calculate the distance based on the arc fault current, system voltage, arc gap, and arc duration.

If the overcurrent protective devices (OCPD) are something other than those covered by IEEE 1584, or if the voltage levels and short circuit currents exceed the IEEE 1584 limitations, then the opening times of the overcurrent protective devices must be analyzed and the corresponding flash protection boundary and incident energy must be calculated by another method.

NFPA 70E TABLE METHOD

Although NFPA 70E (Article 130.3) requires a flash hazard analysis, it also provides an alternate method for determining hazard risk categories and required PPE. This is commonly called the "Table Method" and is based on various tasks to be performed on energized equipment (see NFPA 70E Table 130.(C)(9)(a)). The Table Method may be used in lieu of a complete flash hazard analysis in some cases. However, a complete analysis provides more accurate results.

Caution is advised when using the Table Method. All footnotes listed at the end of NFPA 70E Table 130.7(C)(9)(a) and in any applicable Tentative Interim Amendments must be observed and all prescribed conditions verified. If a task is not listed in NFPA 70E Table 130.7(C)(9)(a) or cannot be verified, then NFPA 70E leaves no other alternative but to do a complete hazard risk assessment using one of the other calculation methods.

STEPS REQUIRED TO USE THE NFPA 70E

TABLE METHOD

Step 1

Once the equipment is identified where work is to be performed, review the up-to-date one-line drawing for information about the available short circuit current and other details about the location of the equipment. If the one-line drawing is not up to date or the available short circuit is not known, it must be determined.

Step 2

Consult NFPA 70E Table 130.7(C)(9)(a) and find the task to be performed. If the desired task to be performed is not listed, the Table Method cannot be used and a complete flash hazard analysis is required.

Step 3

Once you find your task in the table, identify the hazard risk category and determine if voltage rated gloves or tools are required.

Step 4

Verify that the conditions stated in the footnotes for NFPA 70E Table 130.7(C)(9)(a), and any Tentative Interim Amendments such as those stated in NFPA 70E, are applicable to the task.

Step 5

Using NFPA 70E Tables 130.7(C)(10-11) and the corresponding notes in Table 130.7(C)(9)(a), identify the required PPE for the task.

Step 6

The NFPA 70E Table Method does not provide the flash protection boundary, but it must be determined. For systems 600V and below, NFPA 70E defines the FPB as 4 feet. See NFPA 70E for more information on calculating the FPB.

Whether calculations are made or NFPA 70E Table 130.7(C)(9)(a) is used, the results of an electrical hazard analysis (Shock and Flash Hazard Analysis) will determine the following:

- The Limited Approach Boundary
- The Restricted Approach Boundary
- The Prohibited Approach Boundary
- Incident Energy possible at each location
- Flash Protection Boundary
- Hazard Risk Category
- PPE required to work on energized equipment

MINIMIZING ARC FLASH AND OTHER ELECTRICAL HAZARDS

NFPA 70E guidelines and practices are generally considered the "How to" of conforming to the OSHA regulations when performing a hazard assessment, and determining the required PPE.

There are many practices that will help reduce arc flash and other electrical hazards while conforming to OSHA and NFPA 70E regulations and guidelines. Circuit designers and electrical maintenance engineers should carefully consider each of the following recommendations:

1. Design a safer system.
2. Use and upgrade to current-limiting overcurrent protective devices.
3. Implement an electrical safety program.
4. Observe safe work practices.
5. Use personal protective equipment (PPE).
6. Use warning labels.
7. Use an energized electrical work permit.
8. Avoid hazards of improperly selected or maintained overcurrent protective devices.
9. Achieve or increase selective coordination.

1. DESIGN A SAFER SYSTEM

GOALS

When designing a safer system, the following goals and factors should be considered:

- Provide maximum protection to personnel, equipment, and property.
- Meet all applicable code require-

ments (OSHA, NFPA, Building and Insurance codes, etc.)

• Utilize current-limiting overcurrent protective devices to minimize Arc flash hazards.

• Utilize "touch-safe" components to minimize exposure to energized components

• Utilize fuses with blown fuse indication to minimize exposure to energized components while trouble-shooting the circuit.

• Provide selective coordination (only the area where the fault occurs is shut-off)

• Provide a system that is safe to service and maintain.

SYSTEM REQUIREMENTS

Once the goals for your system are established, the selection of the overcurrent protective devices that best meet those goals can be determined. What is the best choice for your application; fuses or circuit breakers? Fuses offer many safety and performance advantages over circuit breakers. Factors to consider include:

• System voltage

Voltage ratings for fuses are standardized at 250, 300, and 600 volts. In comparison, some circuit breakers are rated for dual voltages and are often misapplied.

• Interrupting rating

Most fuses have standard ratings of 200kA at full rated voltage. Circuit breaker interrupting ratings may range from 10kA to 100kA, but the interrupting ratings of many breakers vary with system voltage and type of trip unit.

• System changes resulting in increased available fault current

If your facility grows or the utility makes changes, fault currents have been known to more than double. Interrupting ratings of overcurrent protective devices must be regularly reviewed to insure the device will still protect the system.

• Load current characteristics

Inductive loads such as motors and transformers and even large incandescent lamps have large inrush currents that require circuit breakers to be oversized so that overload protection is sacrificed. Properly selected time-delay fuses can be sized close to load currents and will offer better overload protection.

• Current-limitation

Current-limiting OCPDs reduce damage from major faults. Often devices or equipment can be easily repaired rather than face time-consuming and costly replacement.

• Are your sensitive control devices such as motor starters truly protected?

After a fault, will the units be usable or will they require replacement? Only current-limiting fuses can provide Type 2 Protection. That means you are up and running once the cause of the fault is removed.

2. USE AND UPGRADE TO CURRENT-LIMITING OVERCURRENT PROTECTIVE DEVICES

The incident energy from an arc flash depends on the magnitude of the current and the time it is allowed to flow. Within their current-limiting range, current-limiting devices reduce the peak fault current. Current-limiting fuses have much faster clearing times when operating within their current-limiting range than standard circuit breakers. The faster the overcurrent protective device clears the fault, the lower the I2t and incident energy will be. If current-limiting fuses are used, the incident energy and the hazard risk category may be reduced significantly.

UPGRADE TO CLASS RK1 OR CLASS J CURRENT-LIMITING FUSES

One of the quickest and easiest ways to reduce potential incident energy, lower the hazard risk categories and reduce the required PPE, is to replace UL Class H, K5 or Class RK5 fuses with current-limiting UL Class RK1 or Class J fuses. Upgrading to time-delay Class J fuses affords the best solution by providing the best current limitation while assuring non-interchangeability with non-current-limiting fuses. If an equipment manufacturer has specified a non-time delay fuse, standard Class J fuses are available. If your equipment already has UL Class H fuse clips, it is very easy to replace the Class H or K5 fuses being used with Class RK1 fuses. For a given current and voltage rating, UL Class H, K5, RK5, and RK1 fuses are the same physical size, therefore, it is easy and strongly recommended to upgrade to better fuse protection.

To assure that only current-limiting fuses are used, consider changing to Class J clips or to rejection type clips that will accept only Class R fuses.

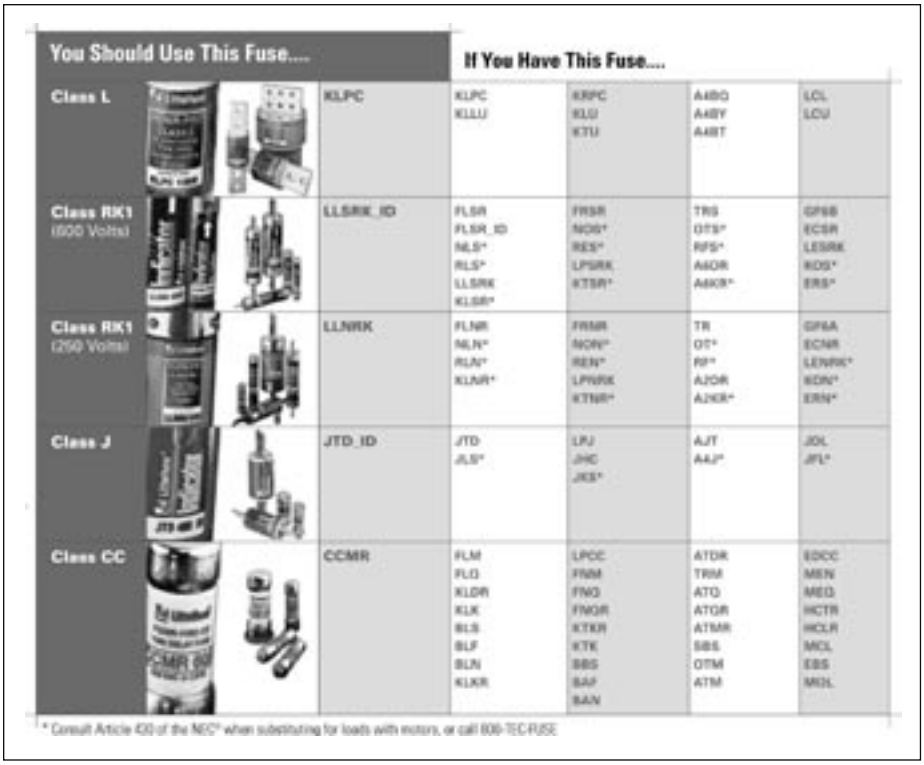
Current-limiting fuses that also offer blown fuse indication such as the Littelfuse Class J JTD_ID and Class RK1 LLSRK_ID can help reduce exposure to electrical hazards. The unique blown fuse indicator decreases downtime by immediately indicating the opened circuit and maximizes safety by minimizing exposure to energized components when trouble-shooting. Replacing non-current-limiting fuses with Littelfuse current-limiting Indicator fuses can significantly reduce the:

• Incident energy from an Arc flash
• The Hazard Risk Category
• The level and type of PPE necessary
• Trouble-shooting and downtime.

3. IMPLEMENT AN ELECTRICAL SAFETY PROGRAM

Electrical Safety Programs protect both employees and employers and provide goals, procedures and work practices to insure safety. NFPA 70E Article 110.7 requires employers to establish an electrical safety program that must be documented and include the minimum following components:

• Scope of the program
• Company philosophy
• Responsibilities
• Establishment of a safety team or



You Should Use This Fuse....		If You Have This Fuse....			
Class L	KLPC	KLPC KLLU	KRPC KLU KTU	A4BQ A4BY A4BT	LCL LCU
Class RK1 (600 Volts)	LLSRK_ID	FLSR FLSR_ID NLS* RLS* LLSRK KLSR*	FRSR NOS* RES* LPSRK KTSR*	TRS OTS* RFS* A6QR A6KR*	GFSS ECSR LESRK KOS* ERS*
Class RK1 (250 Volts)	LLNRK	FLNR NLN* RLN* KLNR*	FRNR NON* REN* LPNRK KTNR*	TR OT* RF* A2QR A2KR*	GFNA ECNR LENRK* KON* ERN*
Class J	JTD_ID	JTD JLS*	LPJ JHC JKS*	AJT AAJ*	JDL JFL*
Class CC	CCMR	FLM FLQ KLDR KLK KLS SLF SLN KLKR	LPCC FNM FNQ FNQR KTKR KTK SBS SAF SAN	ATDR TRM ATQ ATQR ATMR SBS OTM ATM	EDCC MEN MEQ HCTR HCLR MCL EBS MDL

* Consult Article 430 of the NEC® when substituting for loads with motors, or call 800-TEC-FUSE

committee
- Written procedures
- Work instructions
- Identification of industry codes & standards to be adhered to
- Establishment of a documented training program
- Establishment of assessment and audit requirements
- Company policies and enforcement

Increased safety will be possible with the implementation and vigorous enforcement of a well-designed and documented electrical safety program. These programs should be in accordance with all OSHA regulations and nationally recognized safety standards such as NFPA 70E and NEC. For more information on establishing an electrical safety program, refer to NFPA 70E Annex E or NFPA's Electrical Safety Program Book.

4. OBSERVE SAFE WORK PRACTICES

Maintenance

Safe maintenance practices and procedures include properly training employees in the knowledge of the equipment and tools necessary for maintenance and repair. NFPA 70E states that employees "shall be trained in and familiar with the specific maintenance procedures and tests required". Test equipment as well as hand tools are often overlooked and must be insulated and rated for the voltage of the circuits where they will be used. All tools and equipment used for maintenance must also be periodically inspected to ensure they are not damaged (i.e. torn insulation) and are still in good working condition.

DISCONNECT OPERATION

Operating a damaged disconnect switch, whether it's a fusible switch or circuit breaker, can be dangerous. Serious injury could occur if someone is standing in front of a faulty switch or circuit breaker while opening or closing the device. If the handle is on the right-hand side of the device, stand to the right, use your left hand to grasp the handle, turn your face away and then operate it. If the handle is on the left side, reverse the procedure.

Use special caution while operating circuit breakers. If closed into a fault, circuit breakers will trip, drawing an internal arc. The gases from the arc are very hot, and vent through openings in the breaker. These hot gases often vent around the handle and can cause burns unless proper protective equipment is used.

PROPER SERVICE OR REPAIR OF ALL EQUIPMENT OR DEVICES

a) Locate the equipment where work is to be performed. If equipment is running, follow manufacturer's shutdown procedures being sure that all unit switches are off. Do not open any enclosures. Determine if there is adequate working space and that it is clear of obstructions.

b) Locate all disconnecting means providing power to the equipment, including all sources of emergency, alternate, and control power. This must include discharging capacitors and other sources of stored energy. Turn all disconnecting devices to the OFF position and apply lockout/tagout devices as required by OSHA and the company's Electrical Safety Program.

c) While wearing proper personal protective equipment, open the enclosure door or access panels. Test the voltage meter to be used on a known energized source to be sure it is working properly. Test all exposed wires, contacts and other components likely to be energized, insuring that the equipment is in an electrically safe work condition.

EQUIPMENT CONTAINING FUSES

d) If it is suspected there is one or more opened fuses, remove fuses from the circuit using the proper size fuse puller.

Note: The use of Littelfuse Indicator Fuses will minimize time required to locate opened fuses, and help avoid mixing them with good fuses.

e) Place fuses on a non-conductive surface and measure fuse resistance across the ends (endcaps/blades) of the fuse with a meter. If the fuses have knife blades, be sure to test from blade to blade since some types of fuses have

insulated end caps and will give a false reading. High resistance indicates that the fuse may be open.

f) Investigate the circuit to identify the cause of any blown fuses. Look for loose connections or signs of overheating. Correct the problem.

g) Verify the proper fuse class, voltage, ampere, and interrupting ratings before installing replacement fuses. (Caution: because fuse characteristics may vary between manufacturers and fuse classes, fuses should be of the same manufacturer and class for each application.)

h) Examine fuse clips or mountings for signs of corrosion, overheating, or loss of tension.

Service if necessary. Install the replacement fuse with the proper size fuse puller.

EQUIPMENT CONTAINING CIRCUIT BREAKERS

i) After following steps 1 through 3 above, look for circuit breakers and examine to see if any are tripped. Examine the circuit breaker(s) to see if the case or surrounding area shows signs of severe venting indicating a serious fault.

j) Investigate the circuit for the causes of circuit breaker tripping. Correct the problem. If breaker is protecting motor starters, especially IEC or single-purpose type, test the motor starters to be sure they are still functional. If the motor starters have heaters (resistance coils) in the overloads, test the resistance across the heaters to insure they are still functional.

k) Test resistance across the poles of the open circuit breaker to be sure all poles are open and there are no shorts between poles. Close the circuit breaker and measure resistance across the closed poles to insure resistances are within tolerances and are equal from pole to pole.

PLACING EQUIPMENT IN SERVICE

l) Following manufacturer's instructions, close all internal switches and circuit breakers and other procedures necessary for start-up.

m) Close enclosure door(s) and access panels and check the area for other personnel. Remove lockout/tagout devices following OSHA and safety program procedures.

n) Restore power standing to the side of the switch enclosures.

o) Restart equipment following manufacturer's instructions and exercising caution until satisfactory operation is insured.

LOCKOUT/TAGOUT PROCEDURES

OSHA requires that energy sources to machines or equipment must be turned off and disconnected isolating them from the energy source. The isolating or disconnecting means must be either locked or tagged with a warning label. While lockout is the more reliable and preferred method, OSHA accepts tagout to be a suitable replacement in limited situations.

It is estimated that lockout/tagout prevents about 120 fatalities and 50,000 workday injuries annually. Approximately 39 million workers are protected by lockout/tagout practices. Failure to comply with lockout/tagout safety regulations is frequently one of the top five OSHA violations.

In 2004 alone, there were over 4,300 violations cited by OSHA. NFPA 70E Article 120 contains detailed instructions for lockout/tagout and placing equipment in an electrically safe work condition.

APPLICATION OF LOCKOUT/TAGOUT DEVICES

a) Make necessary preparations for shutdown

b) Shut down the machine or equipment

c) Turn OFF (open) the energy-isolating device (fuse/circuit breaker)

d) Apply the lockout or tagout device

e) Render safe all stored or residual energy

f) Verify the isolation and de-energization of the machine or equipment

REMOVAL OF LOCKOUT/TAGOUT DEVICES

a) Inspect the work area to ensure that non-essential items have been removed and that machine or equipment components are intact and capable of operating properly. Especially look for tools or pieces of conductors that may not have been removed.

b) Check the area around the machine or equipment to ensure that all employees have been safely positioned or removed.

c) Make sure that only the employees who attached the locks or tags are the ones that are removing them.

d) After removing locks or tags, notify affected employees before starting equipment or machines.

5. USE PERSONAL PROTECTIVE EQUIPMENT (PPE)

The proper selection and use of personal protective equipment will significantly reduce the risk of arc flash and other electrical hazards to personnel working on energized equipment. OSHA Part 1910.335 (a) states:

"...Employees working in areas where there are potential electrical hazards shall be provided with, and shall use, electrical protective equipment that is appropriate for the specific parts of the body to be protected and for the work to be performed."

A variety of PPE is available from numerous manufacturers. The most common types of protective gear include:

- Non-conductive flame-resistant head, face, and chin protection (hard hats, full face shields, switching hoods, etc.)
- Eye protection (face shields, safety glasses, goggles)
- Body protection resistant to flash flame (shirts, pants, jackets, coveralls)
- Hand and arms protection (insulating gloves and sleeves with leather

PPE REQUIREMENTS

Hazard Risk Category	Required Minimum Arc Rating of PPE (cal/cm²)	Typical Protective Clothing Systems Clothing Description	Minimum Flash Protection Boundary (in.)
0	N/A	1 layer of non-melting, flammable fabric with weight of at least 4.5 oz/yd²	6
1	4	1 layer of a FR shirt and FR pants or FR coverall	15
2	8	1 or 2 layers of FR shirt and FR pants with conventional cotton underwear	45
3	25	2 or 3 layers of FR shirt, FR pants plus FR coverall cotton underwear	60
4	40	3 or more layers of FR shirt, FR pants plus multi-layer flash suit	~120

Derived from NFPA 70E Table 130.7(C)(11)

protectors)

• Foot and leg protection (insulated leg and footwear)

• Insulating blankets or mats

Selection of PPE is dependent on the task to be performed. NFPA 70E Tables 130.7(C)(9), (10), and (11) provide guidance for the selection of personal protective equipment to be used for specific tasks and hazard levels. The Table of PPE requirements above provides typical clothing requirements for Hazard Risk Categories from 0 through 4. Note: Hazard Risk Category 0 still requires some level of protective clothing or equipment. Manufacturers have also developed tables and selection guides based on NFPA 70E recommendations. It is important to note that the level of PPE recommended by NFPA 70E is: "intended to protect a person from arc flash and shock hazards". Even with PPE, some arc flash conditions may result in burns to the skin or include arc blast pressures, toxic vapors, and propelled particles and materials. PPE that is selected should be rated for, or greater than, the minimum arc flash rating required for each hazard risk category.

COMMON PERSONAL PROTECTIVE EQUIPMENT TERMS AND DEFINITIONS

Arc Thermal Performance Exposure Value (ATPV)

The incident energy level (in cal/cm2) that can cause the onset of a second-degree burn as defined in ASTM F 1959 Standard Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing. Personal Protective Equipment will be labeled with a calorie rating (Example: 11 cal/cm2).

V-RATED

Tools and gloves rated and tested for the line-to-line voltage at the area where the work is to be performed.

FLAME RESISTANT (FR)

"The property of a material whereby combustion is prevented, terminated, or inhibited following the application of a flaming or nonflaming source of ignition, with or without subsequent removal of the ignition source."

BREAKOPEN THRESHOLD ENERGY (EBT)

The incident energy level which does not cause flame resistant (FR) fabric break open and does not exceed second-degree burn criteria, as defined in ASTM F 1959.

Standards such as OSHA 1910.137 also specify that protective gear must be maintained and periodically inspected to ensure that it remains in a safe and reliable condition. NFPA also supports this in NFPA 70E Articles 130.7(B), 130.7(C)(8) and 130.7(F). NFPA requirements state that PPE should be inspected before and after each use, and be repaired, cleaned or laundered according to the manufacturer's instructions prior to use. It is also extremely important to avoid contamination of PPE material. Contact with grease, solvents, and flammable liquids may destroy the protection.

6. Use Warning Labels

The National Electrical Code recently recognized arc flash hazards and developed a warning label requirement. NEC

Article 110.16 states:

"1 10.16 Flash Protection:

Switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers that are in other than dwelling occupancies and are likely to require examination, adjustment, servicing, or maintenance while energized shall be field marked to warn qualified persons of potential electric Arc flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment."

While the overall requirement is very comprehensive, the required label format can be very generic. However, if a complete electrical hazard analysis is performed, the preferred approach would be to include the Hazard Risk Category, Flash Protection Boundary, Incident Energy available, level of PPE required, system voltage, and shock protection boundaries on labels. See Figures 10 and 11 for examples of typical warning labels:

The use of detailed warning labels not only increases safety, but also minimizes the time required to identify

minimum levels of PPE. Other types of warning labels should also be used to include information about proper fuse replacements, location of disconnects and other sources of power, etc. Warning labels can be applied directly to pieces of equipment or on enclosure doors. Computer programs and adhesive blank labels make it easy to create labels for almost every purpose.

7. USE AN ENERGIZED ELECTRICAL WORK PERMIT

NFPA 70E requires that a detailed written Energized Electrical Work Permit must be used and signed by responsible management whenever work is performed on live energized equipment.

8. AVOID HAZARDS OF IMPROPERLY SELECTED OR MAINTAINED OVERCURRENT PROTECTIVE DEVICES

Whether in the design or maintenance of an electrical system, hazards exist if the proper overcurrent device is not selected and applied. Circuit breakers and other electrical equipment must be maintained and serviced regularly to ensure that they will operate properly when needed. Unfortunately, in many industries and especially during economic turndowns, the tendency is to limit or eliminate regularly scheduled maintenance on circuit breakers and other electrical equipment.

However, the potential costs associated with OSHA violations, liability lawsuits, workers compensation, equipment replacement, and lost production far exceeds the costs of regular testing and maintenance of circuit breakers and other electrical equipment.

OSHA 29 CFR 1910.334(b)(2)

"Reclosing circuits after protective device operation. After a circuit is deenergized by a circuit protective device, the circuit may NOT be manually reenergized until it has been determined that the equipment and circuit can be safely re-energized. The repetitive manual reclosing of circuit breakers or reenergizing

Minimum Label Requirements

Figure 10. Minimum Label Requirements

Preferred Label Approach

Figure 11. Preferred Label Approach

circuits through replaced fuses is prohibited.

NOTE: When it can be determined from the design of the circuit and the overcurrent devices involved that the automatic operation of a device was caused by an overload rather than a fault condition, no examination of the circuit or connected equipment is needed before the circuit is reenergized."

In this section of the regulations, OSHA recognizes the importance of knowing why the overcurrent protective device has opened.

If the fuse or circuit breaker opened due to an overload, no examination of the circuit or connected equipment is necessary. However, if the overcurrent protective device opened due to a short circuit fault, catastrophic results can occur if the fuse or circuit breaker is replaced or closed on the short circuit before it is corrected.

This is especially important for circuit breakers and switches because short circuit currents can permanently damage the equipment to the point that it will not operate safely when reenergized.

CIRCUIT BREAKERS

Circuit breakers, like fuses, are rated to safely interrupt their maximum interrupting current only once. Molded case circuit breakers (commonly referred to as MCCBs) must meet the requirements of UL489, "Standard for Safety," Molded-Case Circuit Breakers, Molded Case Switches and Circuit Breaker Enclosures. This standard allows manufacturers to list their circuit breakers at varying degrees of available fault currents, current-limiting ability and other characteristics. They must be applied within the maximum limitations of their ratings.

Circuit breaker manufacturers typically recommend that their circuit breakers be cycled ON and OFF at least once each year to keep the tripping mechanism from seizing under certain environmental conditions. Cycling circuit breakers ON and OFF manually may help keep the switching mechanism from seizing, but may not guarantee that the tripping mechanism will operate properly. Some manufacturers also recommend that their circuit breakers be periodically tested and recalibrated under carefully controlled conditions.

When testing time-current characteristics, recommendations state the circuit breaker being tested must be at room temperature. This practice would increase equipment downtime while the circuit breaker to be tested cools down after it is removed from service.

The National Electrical Manufacturers Association (NEMA) has published standard AB 4-2003 entitled, "Guidelines for Inspection and Preventive Maintenance of Molded Case Circuit Breakers Used in Commercial and Industrial Applications." It deals exclusively with the maintenance and care of Molded Case Circuit Breakers to provide reliable protection. The expected lifetime of a circuit breaker, however, depends on circuit conditions and its' environment. Standard AB 4-2003 emphasizes that safe work practices include regular periodic maintenance, and investigating what caused the circuit breakers to operate prior to reenergizing the circuit — similar to OSHA 29 CFR 1910.334(b)(2). There are other published industry standards for maintenance of large Air Power Circuit Breakers. Preventive maintenance of these circuit breakers should be performed at least annually, and after interruption of a fault some 20 or more steps are required before placing the circuit breaker back in service.

The Institute of Electrical and Electronic Engineers (IEEE) has also published Standard 493-199 7, otherwise known as the "Gold Book," entitled, Recommended Practice For the Design Of Reliable Industrial And Commercial Power Systems. The IEEE studied failure statistics of typical industrial and commercial electrical distribution systems and components over several years prior to 1974 and more recently in 1996. The results of the 1996 study concluded nearly 1/3 of all circuit breakers that failed while in service could have been avoided if proper maintenance and testing was performed.

Article 225.3 of NFPA 70E requires that if a circuit breaker interrupts a fault at or near its interrupting rating, it must be inspected by a trained technician and tested, repaired or replaced in accordance with the manufacturer's specifications.

If proper maintenance and repair is neglected, circuit breakers may fail to open or may open more slowly than when first calibrated. The IEEE study noted that circuit breaker failures caused excessive equipment damage, blackouts, unexpected repair and replacement costs, lost production, scrap production, and most importantly, severe blast and burn injuries to personnel. Proper care and maintenance of circuit breakers must be part of any Electrical Safety Program.

Other common safety hazards involve using overcurrent protective devices with improper interrupting ratings. Standard circuit breakers have relatively low interrupting ratings (typically 10,000 to 100,000 AIC) when compared to fuses (200,000 AIR). The circuit breaker's low interrupting rating may not be an initial hazard, but as available fault currents rise from the utility, a dangerous situation is created.

During service upgrades, circuit breakers with low interrupting capacities may have to be replaced by higher rated devices or protected by fuses in order to lower fault currents.

NON-CURRENT-LIMITING FUSES

Another potential electrical hazard is the use of non-current-limiting fuses including "renewable" fuses. Although fuse standards and fuse technology have changed greatly, many older machines and equipment may contain Class H (one-time or renewable) or K5 one-time fuses. The continued use of these fuses especially where available fault currents exceed their interrupting ratings can be catastrophic. In addition to being non-current-limiting, Class H and K5 fuses have lower interrupting ratings than the

Class R or J fuses. Just like non-current-limiting circuit breakers, the Class H and K5 fuses may permit much higher current to flow for a much longer time, increasing risk to workers and the equipment. The incident energy of an arc flash could be deadly to an unsuspecting worker who is not properly protected.

9. ACHIEVE OR INCREASE SELECTIVE COORDINATION

When an overcurrent occurs in a system, only the overcurrent protective device immediately on the line side of the overcurrent should open. This reduces unnecessary shutdown of other equipment and simplifies locating the problem. Such systems are defined as "selectively coordinated." Refer to Figure 12.

If a system is not selectively coordinated, a fault at point A can cause the fuses or circuit breakers at points B, C, and D to open, needlessly shutting off power to two or more unaffected areas. In a selectively coordinated system, a fault at point A will cause only the fuse or circuit breaker immediately before the fault to open, keeping power supplied to the rest of the feeder and branch circuits throughout the facility.

Feeder circuit breakers or fuses are typically rated at least twice that of the downstream devices. An arc flash that opens the upstream devices means that the total I2t heat energy and consequently, incident energy, is determined by the largest upstream device. In this situation, the electrical system is not selectively coordinated, and the incident energy increases as a result of the time elapsed before the upstream overcurrent protective device clears the fault.

Achieving a selectively coordinated system not only reduces downtime and the risk of arc flash exposure, but Articles 240.12, 700.27, 701.18 and 620.62 of the National Electrical Code require it. These code specifications refer to emergency circuits or potential life saving circuits such as alarm circuits, emergency lighting, and elevator circuits. For example, during an emergency or in a building with

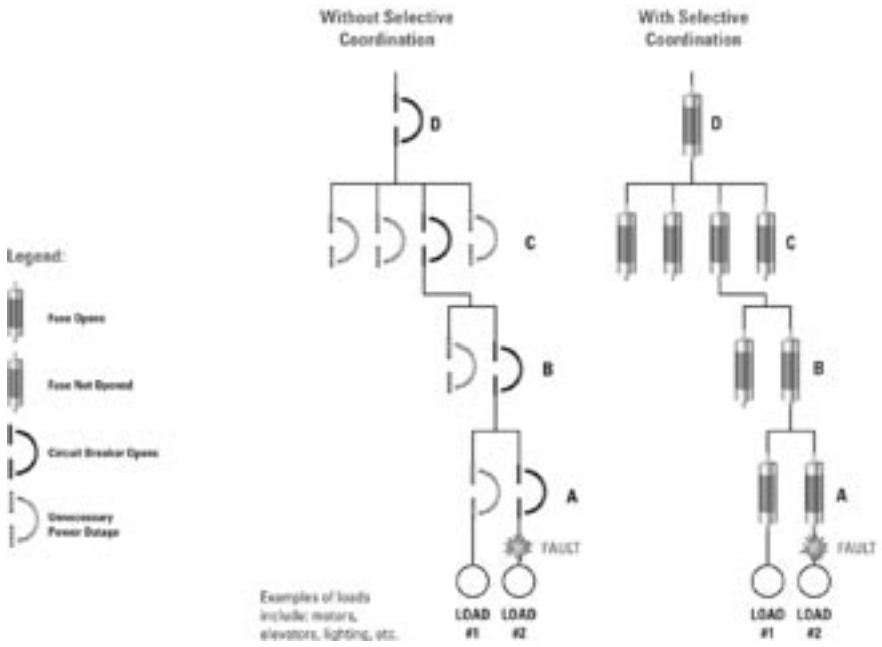


Figure 12. Selective Coordination

an elevator, an overcurrent on one elevator motor must not cause the feeder circuit to open all other elevator circuits, or alarm systems.

It is also unsafe to replace blown fuses with slightly higher ampere ratings in order to compensate for nuisance openings. Doing so will defeat selective coordination and can dramatically increase the amount of risk to workers if an arc flash occurs. In order to decrease downtime and reduce the risk of arc flash exposure to unsuspecting workers, it is best to replace non-current-limiting fuses and circuit breakers with more accurately rated time-delay current-limiting fuses such as the Littelfuse Class RK1 LLSRK_ID series.

Electrical safety is important for everyone. Employees working on electrical systems are at risk every day, but with the properly designed overcurrent protection system, the implementation of safe work practices and the utilization of the appropriate PPE, risk can be minimized.

ELECTRICAL SAFETY SUMMARY

Here is a brief review of some basic electrical safety concepts.

1) Unless there is a compelling safety issue such as life-support equipment, alarm systems, hazardous location ventilation, or lighting required for safety, OSHA requires that circuits be de-energized and the system be placed in an electrically safe work condition before any work is performed.

2) When placing equipment in an electrically safe work condition, always follow proper lockout/tagout procedures.

3) An electrical hazard analysis must be performed on all circuits 50 volts and higher that may be worked on while energized.

4) The hazards must be identified and warning labels must be applied to all equipment that may be worked on while energized.

5) Workers must be trained on the equipment, hazards and safety precautions, and be certified as "qualified" to work on energized equipment. Training and certification must be documented.

6) All work performed on energized equipment must be preceded by a job briefing and a signed energized electrical work permit.

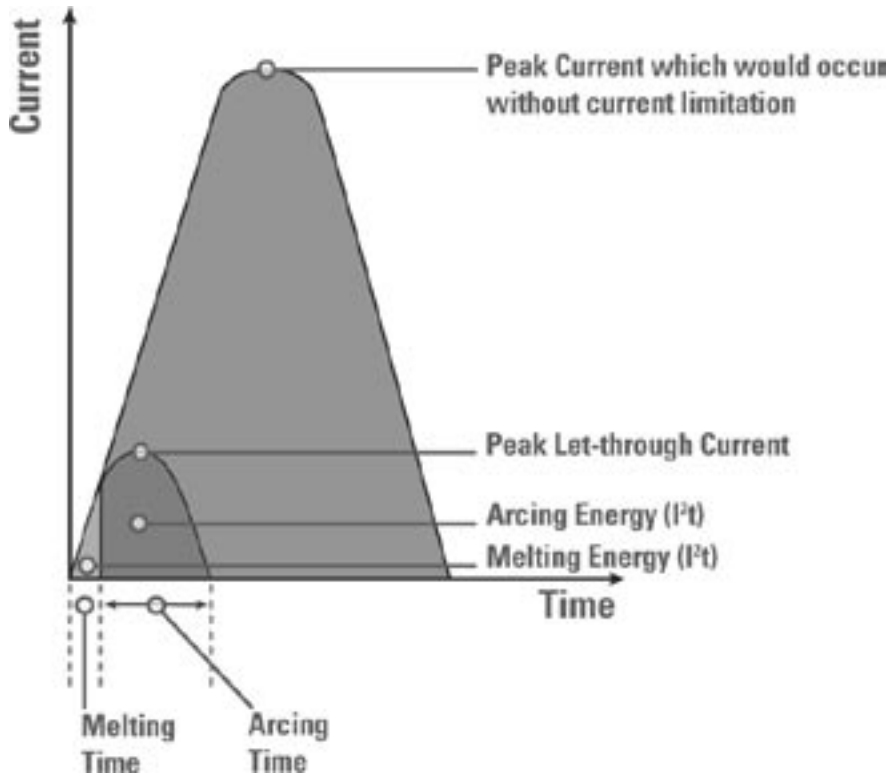


Figure 13. Current Limitation

7) When working on or approaching energized circuits, proper protective clothing must be worn. The minimum flame retardant clothing, safety glasses, and protective gloves and equipment must meet OSHA and NFPA 70E guidelines. Protective insulating blankets and mats are also used to minimize exposure.

8) Be certain there is adequate lighting for the tasks to be performed. Portable lighting must be fully insulated so that it will not accidentally cause short circuits when used near energized components.

9) Use barricades or barriers to warn unqualified individuals from entering the area.

1 0) Be prepared for the unexpected. Make sure emergency communications and trained medical personnel are available if something goes wrong.

11) Use current-limiting overcurrent protective devices wherever possible to reduce the potential electrical hazards.

Electrical Safety in the workplace can only be attained when workers and employers diligently follow OSHA and industry accepted standards and regulations. It is our sincere hope and desire that the information provided here has been helpful in informing the reader of the importance of electrical safety while providing methods and information on how to effectively and safely reduce electrical hazards.

ELECTRICAL SAFETY TERMS AND DEFINITIONS

A.I.C. or A.I.R.:
See Interrupting Capacity.

Ambient Temperature:

The air temperature surrounding a device. For fuses or circuit breakers in an enclosure, the air temperature within the enclosure.

Ampacity:

The current in amperes that a conductor can carry continuously under the conditions of use without exceeding its temperature rating. It is sometimes informally applied to switches or other devices. These are more properly referred to by their ampere rating.

Ampere Rating:

The current rating, in amperes, that is marked on fuses, circuit breakers, or other equipment. It is not to be inferred that equipment or devices can continuously carry rated amperes. Various derating factors may apply. Refer to NEC for further information.

Ampere-Squared-Seconds (I^2t):

The heat energy passed by a fuse or circuit breaker from the instant the fuse links melt or circuit breaker contacts part (arcing time). It is equal to the rms arcing current squared multiplied by the arcing time.

Approach Boundaries:

Protection boundaries established to protect personnel from shock.

Arcing I^2t:

The heat energy passed by a fuse during its arcing time. It is equal to the rms arcing current squared multiplied by the arcing time.

Arcing Current (See Figure 13):

The current that flows through the fuse after the fuse link has melted and until the circuit is interrupted.

Arcing-fault:

A short circuit that arcs at the point of fault. The arc impedance (resistance) tends to reduce the short-circuit current. Arcing faults may turn into bolted faults by welding of the faulted components. Arcing faults may be phase-to-phase or phase-to-ground.

Arc Blast:

A pressure wave created by the heating, melting, vaporization, and expansion of conducting material and surrounding gases or air.

Arc Flash:

The sudden release of heat energy and intense light at the point of an arc. Can be considered a short circuit through the air, usually created by accidental contact between live conductors.

Arc Gap:

The distance between energized conductors or between energized conductors and ground. Shorter arc gaps result in less energy being expended in the arc, while longer gaps reduce arc current. For 600 volts and below, arc gaps of 1.25 inches (32 mm) typically produce the maximum incident energy.

Arc Rating:

A rating assigned to material(s) that relates to the maximum incident energy the material can resist before break-open of the material or onset of a second-degree burn. The arc rating is typically shown in cal/cm2.

Arcing Time:

(See Figure 13): The time between the melting of a fuse link or parting of circuit breaker contacts, until the overcurrent is interrupted.

Arc Voltage:

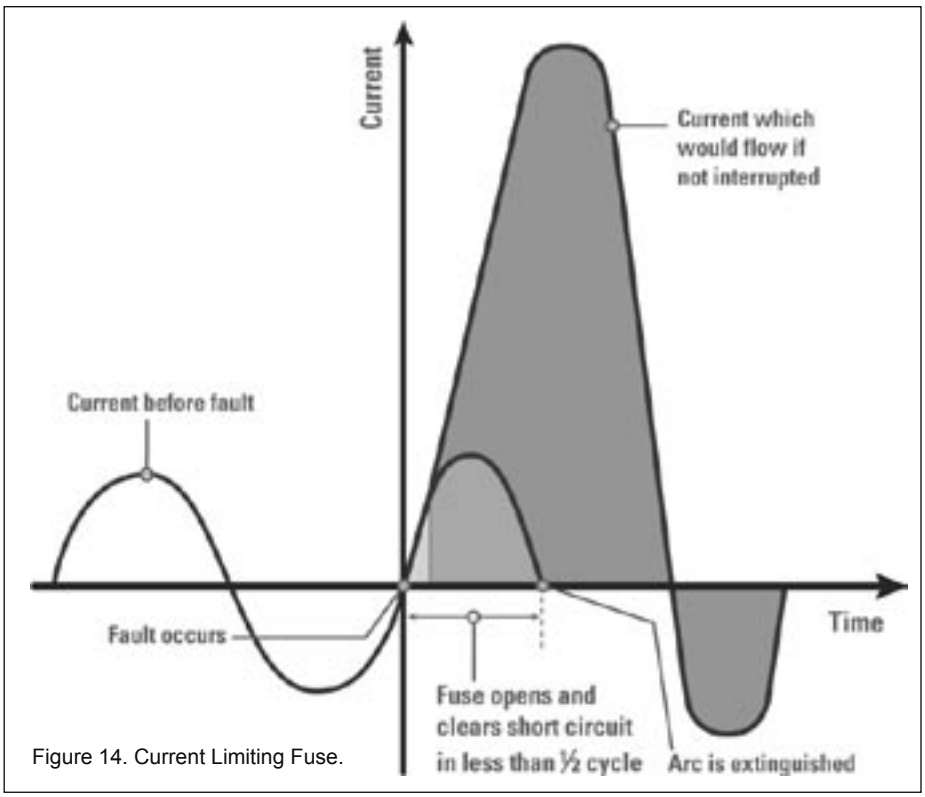
A transient voltage that occurs across an overcurrent protection device during the arcing time. It is usually expressed as peak instantaneous voltage (Vpeak or Epeak), but sometimes as rms voltage.

Asymmetrical Current:

AC current that is not symmetrical around the zero axis. Usually caused by a fault in circuits with low power factors. (See Power Factor and Symmetrical Current).

Available Short Circuit Current:

(also Available or Prospective Fault Current): The maximum rms symmetrical current that would flow at a given point in a system under bolted-fault conditions. Short-circuit current is maximum during the first halfcycle after the fault occurs. (See definitions of Bolted Fault and Symmetrical Current.)


Current
Current which would flow if not interrupted
Current before fault
Fault occurs
Time
Fuse opens and clears short circuit in less than ½ cycle
Arc is extinguished
Figure 14. Current Limiting Fuse.

Bolted Fault:

A short circuit that has no electrical resistance at the point of the fault. It results from a firm mechanical connection between two conductors, or a conductor and ground. Bolted faults are characterized by a lack of arcing. Examples of bolted faults are a heavy wrench lying across two bare bus bars, or a crossed-phase condition due to incorrect wiring.

Boundaries of Approach:

Protection boundaries established to protect personnel from shock and arc flash hazards.

Calorie:

The amount of heat needed to raise the temperature of one gram of water by one degree Celsius. 1 cal/ cm2 is equivalent to the exposure on the tip of a finger by a cigarette lighter for one second.

Clearing I2t (Also Total Clearing I2t):

The ampere-squared seconds (I2t) through an overcurrent device from the inception of the overcurrent until the current is completely interrupted. Clearing I2t is the sum of the Melting I2t and the Arcing I2t.

COORDINATION OR COORDINATED SYSTEM:

See Selective Coordination.

Current-Limiting Fuse (Figure 14):

A fuse which, when interrupting currents within its current-limiting range, reduces the current in the faulted circuit to a magnitude substantially less than that obtainable in the same circuit if the device was replaced with a solid conductor having comparable impedance. To be labeled "current-limiting", a fuse must mate with a fuse block or fuse holder that has either a rejection feature or dimensions that will reject non-current-limiting fuses.

Current-Limiting Range:

For an individual overcurrent protective device, the current-limiting range begins at the lowest value of rms sym-

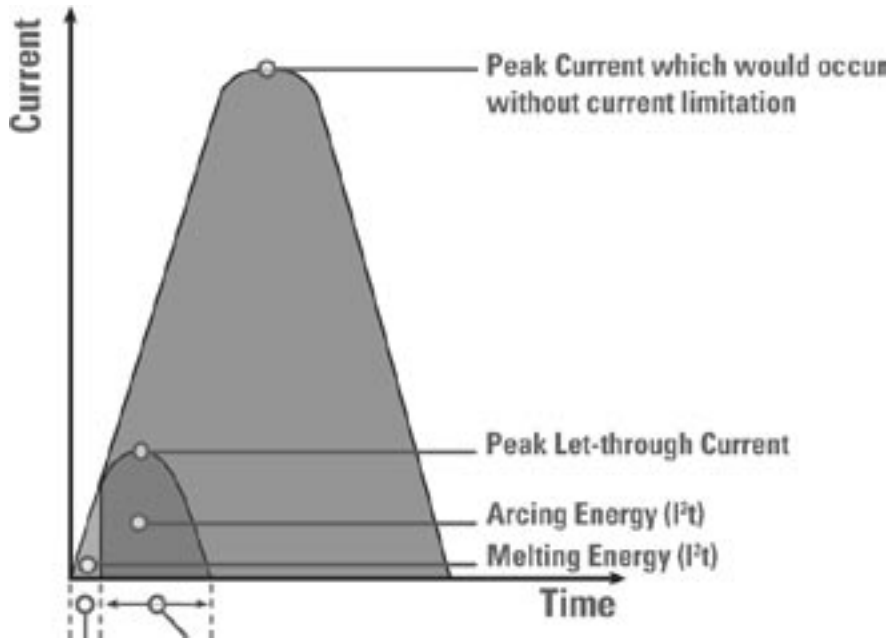


Figure 15. Peak let-through.

metrical current at which the device becomes current-limiting (the Threshold Current) and extends to the maximum interrupting capacity of the device.

Current Rating:

See Ampere Rating.

De-energized:

Equipment or components that have had all energy sources removed.

Device Rating:

Refers to the standard ampere rating of a device as defined by NEC Article 240.6. Standard ampere ratings ranges from 1 to 6000 amperes.

Distance to Arc:

Refers to the distance from the receiving surface to the arc center. The value used for most calculations is typically 18 inches.

Electrical Hazard:

A dangerous condition caused by equipment failure or contact with an energized conductor. Hazards include shock, arc flash, burns and arc blasts.

Electrical Hazard Analysis:

A study to identify the potential electrical hazards that may be exposed to personnel. The analysis should address both shock and arc flash hazards.

Electrically Safe Work Condition:

Condition where the equipment and/or circuit components have been disconnected from electrical energy sources, locked/tagged out, and tested to verify all sources of power are removed.

Energized:

Refers to components within a system being connected to a "live" voltage source.

Fault:

Same as Short-Circuit and used interchangeably.

Fault Current:

Same as Short-Circuit Current.

Flash Hazard Analysis:

A study that analyzes potential exposure to arc flash hazards. The outcome of the study establishes Incident Energy levels, Hazard Risk Categories, Flash Protection Boundaries, and required PPE. It also helps define safe work practices.

Flash Protection Boundary:

A protection boundary established to protect personnel from arc flash hazards. The flash protection boundary is the distance at which an unprotected worker can receive a second-degree burn to bare skin.

Fuse:

An overcurrent protective device consisting of one or more current-carrying elements enclosed in a body fitted with contacts so that the fuse may be readily inserted into or removed from an electrical circuit. The elements are heated by the current passing through them, thus interrupting current flow by melting during specified overcurrent conditions.

Ground-fault:

A short circuit caused by insulation breakdown between a phase conductor and a grounded object or conductor.

Hazard Risk Category:

A classification of risks (from 0 to 4) defined by NFPA 70E. Each category requires PPE and is related to incident energy levels.

Incident Energy:

The amount of thermal energy impressed on a surface generated during an electrical arc at a certain distance from the arc. Typically measured in cal/cm^2.

I^2t:

Symbol for Ampere-Squared-Seconds. A means of describing the thermal energy generated by current flow. When a fuse or current-limiting circuit breaker is interrupting currents within their current-limiting range, the term is expressed as melting, arcing, or total clearing I^2t. (See Melting I^2t, Arcing I^2t, and Clearing I^2t).

Instantaneous Peak Current (Ip or Ipeak):

The maximum instantaneous current value developed during the first half-cycle (180 electrical degrees) after fault inception. The peak current determines magnetic stress within the circuit.

Interrupting Capacity (AIC):

The highest available symmetrical rms alternating current (for DC the highest direct current) at which the protective device has been tested, and which it has interrupted safely under standardized test conditions. The device must interrupt all available overcurrents up to its interrupting capacity. Also commonly called Interrupting Rating.

Interrupting Rating (IR, I.R., AIR or A.I.R.):

The highest rms symmetrical current, at specified test conditions, which the device is rated to interrupt. The difference between Interrupting Capacity and Interrupting Rating is in the test circuits used to establish the ratings.

Limited Approach Boundary:

An approach boundary to protect personnel from shock. A boundary distance is established from an energized part based on system voltage. To enter this boundary, unqualified persons must be accompanied by qualified person and use PPE.

Melting I^2t:

The heat energy created by an overcurrent required to melt the fuse link(s). It equals the rms current (or DC current) squared, multiplied by the melting time in seconds.

For times less than 0.004 seconds, melting I^2t approaches a constant value for a given fuse.

Overcurrent:

Any current larger than the equipment, conductor, or devices are rated to carry under specified conditions.

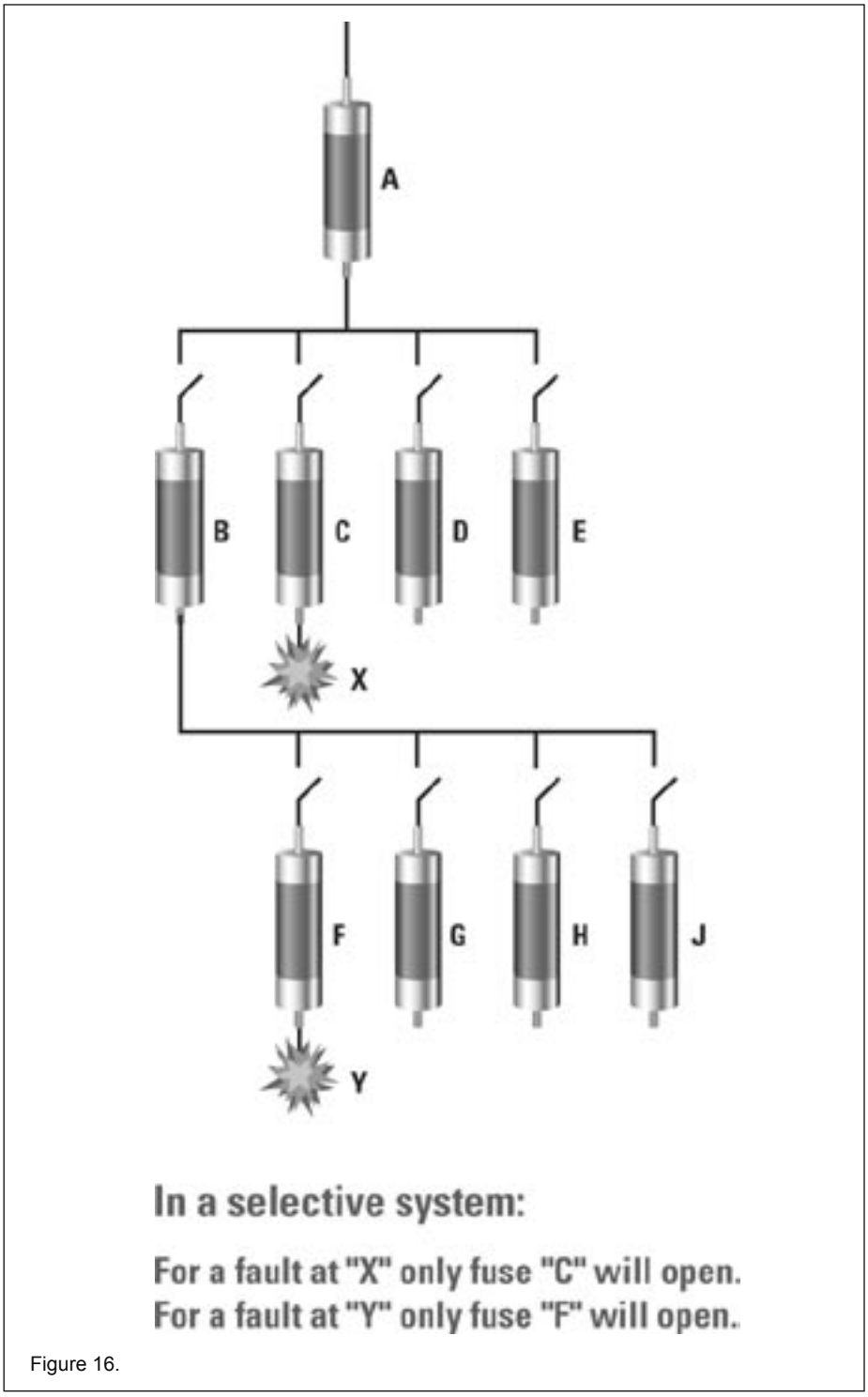


Figure 16.

Overload:

An overcurrent that is confined to the normal current path (e.g., not a short circuit), which, if allowed to persist, will cause damage to equipment and/or wiring.

(See Figure 15):

The maximum instantaneous current that passes through an overcurrent protective device during its total clearing time when the available current is within its current-limiting range.

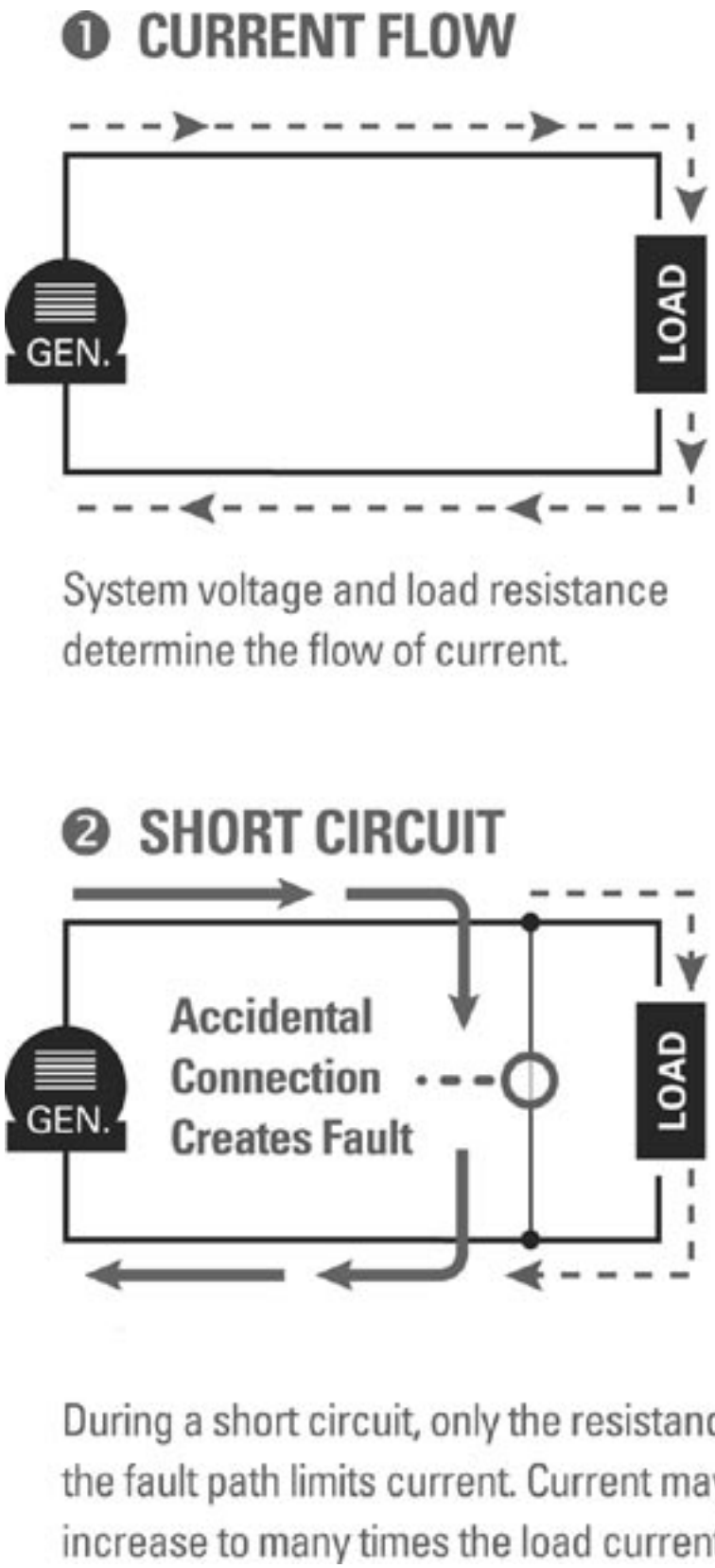

1 CURRENT FLOW
GEN.
LOAD
System voltage and load resistance determine the flow of current.
2 SHORT CIRCUIT
GEN.
Accidental Connection Creates Fault
LOAD
During a short circuit, only the resistance of the fault path limits current. Current may increase to many times the load current.

Figure 17.

Power Factor (X/R):

As used in overcurrent protection, power factor is the relationship between the inductive reactance (X) and the resistance (R) in the system during a fault. Under normal conditions, a system may be operating at a 0.85 power factor (85%). When a fault occurs, much of the system resistance is shorted out and the power factor may drop to 25% or less. This may cause the current to become asymmetrical. See definition of Symmetrical Current.

PPE:

An acronym for Personnel Protective Equipment. It can include clothing, tools, and equipment.

Prohibited Approach Boundary:

An approach boundary to protect personnel from shock. Work in this boundary is considered the same as making direct contact with an energized part. Only qualified persons are allowed to enter this boundary and they must use PPE.

Protection Boundaries:

Boundaries established to protect personnel from electrical hazards.

Qualified Person:

A person who is trained and knowledgeable on the construction and operation of the equipment and can recognize and avoid electrical hazards that may be encountered.

Rating:

A designated limit of operating characteristics based on definite conditions, such as current rating, voltage rating and interrupting rating.

Renewable Fuse:

A fuse that may be readily restored to service by replacing the renewable element after operation.

Restricted Approach Boundary:

An approach boundary to protect per-

sonnel from shock. A boundary distance is established from an energized part based on system voltage. Only qualified persons are allowed in the boundary and they must use PPE.

Selective Coordination (SEE FIGURE 16):

In a selectively coordinated system, only the protective device immediately on the line side of an overcurrent opens. Upstream protective devices remain closed. All other equipment remains in service, which simplifies the identification and location of overloaded equipment or short circuits.

Shock:

A trauma subjected to the body by electrical current. When personnel come in contact with energized conductors, it can result in current flowing through their body often causing serious injury or death.

Short Circuit (See Figure 17):

A current flowing outside its normal path. It is caused by a breakdown of insulation or by faulty equipment connections. In a short circuit, current bypasses the normal load. The amount of current is determined by the system impedance (AC resistance) rather than the load impedance. Short-circuit currents may vary from fractions of an ampere to 200,000 amperes or more.

Short-circuit Rating:

The maximum rms symmetrical short-circuit current (for DC equipment DC current) at which a given piece of equipment has been tested under specified conditions, and which at the end of the test, is in essentially the same condition as prior to the test. Short-circuit ratings (also called withstand ratings) apply to equipment that will be subjected to fault currents, but which are not required to interrupt them. This includes switches, busway (bus duct), switchgear and switchboard structures, motor control centers and transformers. Most short-circuit ratings are based on tests which last three complete electrical cycles (0.05 seconds). Some equipment may have reduced short-circuit rating for times longer than 3 cycles. Refer to manufacturer's literature. If the equipment is protected during the test by fuses or by a circuit breaker with instantaneous trips, the test duration is the time required for the overcurrent protective device to open the circuit.

When so protected during testing, the equipment instructions and labels must indicate that the equipment shall be protected by a given fuse class and rating, or by a specific make, type, and rating of circuit breaker. Certain circuit breakers equipped with short-delay trip elements instead of instantaneous trip elements may have withstand (short-circuit) ratings in addition to their interrupting rating. The withstand rating is the fault current the breaker must be able to withstand for a specified time or if it is protected by a fuse or another circuit breaker in series with it. They may also have reduced interrupting ratings.

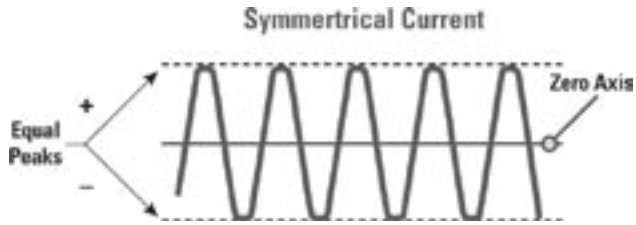


Figure 18.

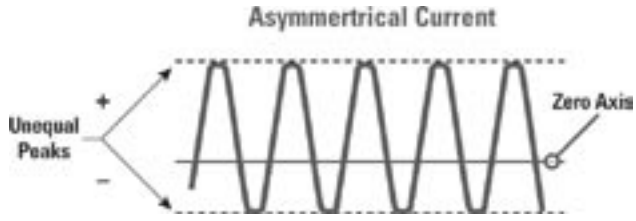


Figure 19.

Symmetrical Current:

The terms "Symmetrical Current" and "Asymmetrical Current" describe an AC wave's symmetry around the zero axis.

The current is symmetrical when the peak currents above and below the zero axis are equal in value, as shown in Figure 18. If the peak currents are not equal, as shown in Figure 19, the current is asymmetrical. The degree of asymmetry during a fault is determined by the change in power factor (X/R) and the point in the voltage wave when the fault occurs.

System Voltage:

The phase-to-phase or three-phase voltage(s) at the point being evaluated.

Threshold Current:

The minimum current for a given fuse size and type at which the fuse becomes current-limiting. It is the lowest value of available rms symmetrical current that will cause the device to begin opening within the first 1/4 cycle (90 electrical degrees) and completely clear the circuit within 1/2 cycle (180 electrical degrees). The approximate threshold current can be determined from the fuse's peak let-through charts. See Figure 20.

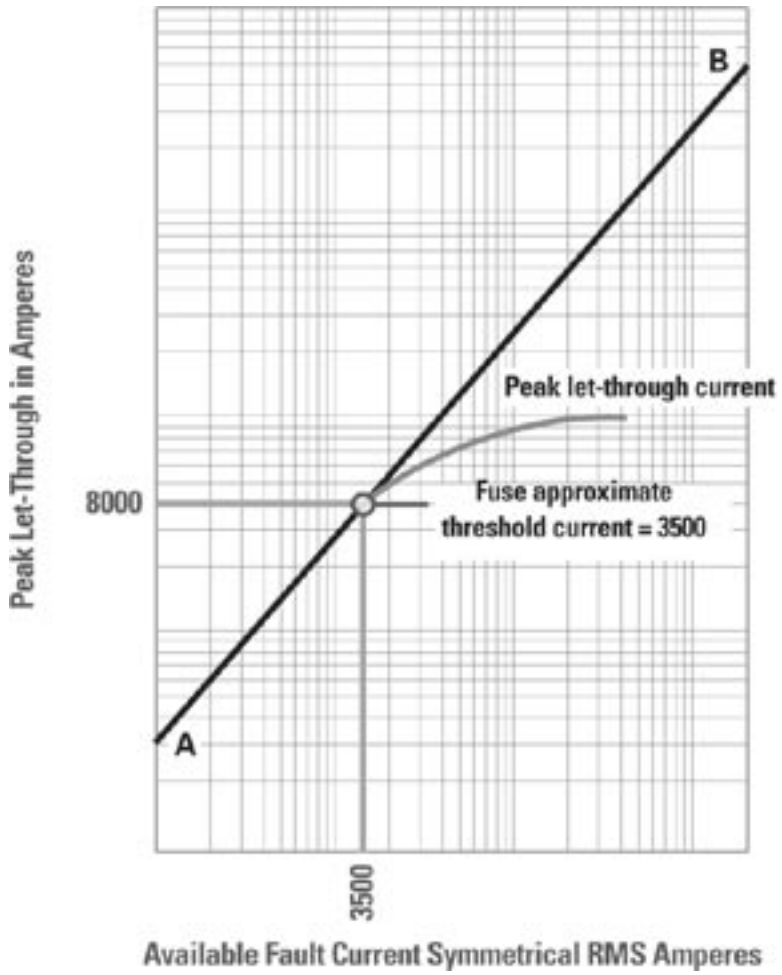


Figure 20.

Threshold Ratio:

The threshold current divided by the ampere rating of a specific type or class of overcurrent device. A fuse with a threshold ratio of 15 becomes current-limiting at 15 times its current rating.

Unqualified Person:

A person that does not possess all the skills and knowledge or has not been trained for a particular task.

Voltage Rating:

The maximum rms AC voltage and/or the maximum DC voltage at which the device is designed to operate. For example, fuses rated 600 volts may be applied at any system voltage less than or equal to their rating. [There are no specific rules for applying AC fuses in DC circuits.] Fuses used on DC circuits must have proper DC voltage ratings. Circuit breaker ratings are more complex since some breakers may have dual voltage ratings.

Withstand Rating:

See Short-Circuit Rating.

Arc Flash Basics: Testing Update

By M. Lang and T. Neal, Ferraz Shawmut

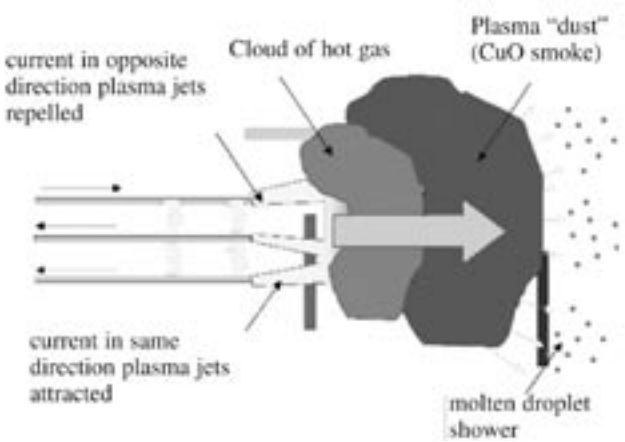

current in opposite direction plasma jets repelled
Cloud of hot gas
Plasma "dust" (CuO smoke)
current in same direction plasma jets attracted
molten droplet shower

Fig. 1: The general directional nature of an arc; this depiction does not reflect chaotic behaviour.

1. INTRODUCTION

The last 15 years have seen tremendous progress being made in protecting workers against the heat energy associated with arc flash. Research into such injuries in the United States during the 1990s showed that over 2,000 workers were admitted to burn centers each year. One major area of improvement has been the steps taken to get workers into safer clothing. The arc rating system developed by ASTM and the development of the predictive equations identified in NFPA 70E and IEEE 1584 have been instrumental in this effort.

At the center of these developments has been arc flash testing. The arc thermal performance value (ATPV) of electrical personal protective equipment (PPE) relies on arc flash tests performed in a high power test lab. The IEEE 1584 equations were developed empirically from arc flash tests performed in North American test labs from the late 1990s through 2002.

Recent research into arc flash phenomena, however, indicates that workers could be underprotected against the heat generated during an arc flash event. Test results presented at IEEE conferences [1-3] and at the 2007 IEEE Electrical Safety Workshop show that different configurations of electrodes (conductors) yielded heat energy higher than current predictions due to the directional nature of the arc development. Additionally, initial tests of PPE, when placed within this directional plasma flow, did not provide the level of thermal protection predicted by its Arc Rating as determined by the ASTM test method.

2. DIRECTIONAL NATURE OF ARC DEVELOPMENT

Unrestricted high-current arcs move according to magnetic forces to increase the area of the current loop. Currents flowing in the opposite direction in parallel conductors give rise to forces that drive the arc away from the source to the end of the conductors where they typically burn off the tips of electrodes (busbars).

The behaviour of a 3-phase arcing fault in equipment is very chaotic, involving rapid and irregular changes in arc geometry due to convection, plasma jets and electromagnetic forces. Arc extinction and re-ignition, changes in arc paths due to restriking and reconnection across electrodes and plasma parts and many other effects add to this chaotic nature and make it difficult to create equations for accurate predictions of its properties (e.g. impedance). Although it does not capture this chaotic behaviour, Fig. 1 demonstrates an arc's general directional nature. The alternating 3-phase current creates successive attractive and repulsive magnetic forces, dramatically moving the plasma jets which feed an expanding plasma cloud. The cloud is driven outward, away from the tips, creating "plasma dust" as the highly energized molecules in the plasma cool, and recombine into various materials. The molten electrode material ejected off the tips also is in this flow.

3. ARC FLASH HAZARDS

When the arc is being established, current begins passing through ionized air generating massive quantities of heat. Large volumes of ionized gases, along with metal from the vaporized conductors, are explosively expelled. As the arc runs its course, electrical energy continues to be converted into extremely hazardous energy forms. Hazards include the immense heat of the plasma, radiated heat, large vol-

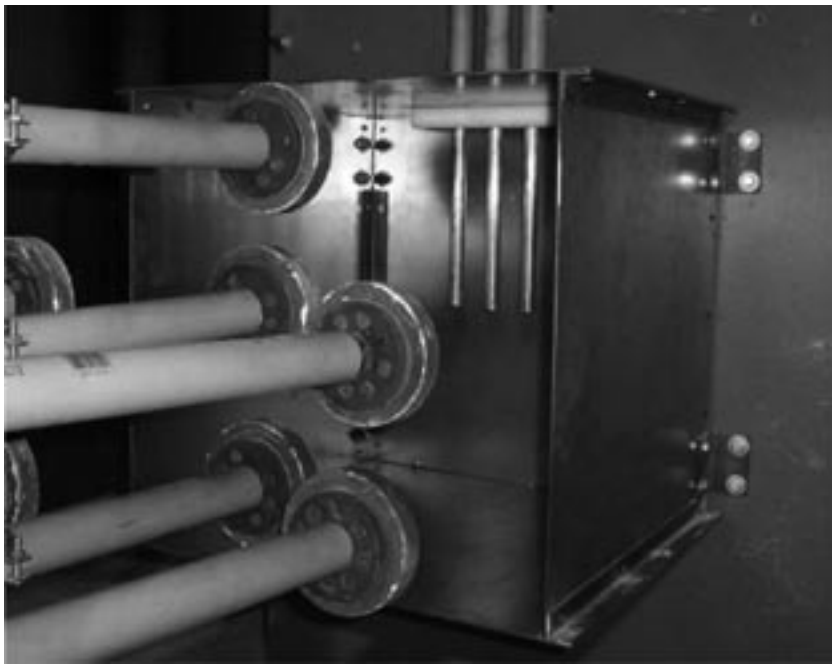


Fig. 2: Open-tip vertical electrode configuration

Fig. 3: Front view of arc development from vertical test 3ms into event.

umes of toxic smoke, molten droplets of conductor material, shrapnel, extremely intense light and a pressure wave from the rapidly expanding gases.

Recent tests have shown that an object in the expanding plasma cloud is directly exposed to the highest heat of the event. Temperatures greater than 15,000 C have been cited for this area. In addition to the convective heat transfer from the plasma, this object is directly exposed to the molten metal ejected from the electrode tips and radiated heat from surrounding plasma.

Objects close to the arc but outside of the plasma jets are not likely subjected to as high a quantity of heat. Exposure is predominately radiant heat, but includes convective flow from the thermal expansion of the gases.

Objects in line with the electrodes but distant from the plasma jets receive lower convective heating and less radiant heat and molten metal spray.

The amount of heat absorbed varies with the method of heat transfer and receiving surface properties. For example, the amount of heat transferred from a mass of molten copper to a surface area would be greater if it adhered to the object instead of contacting it for a brief time.

4. CURRENT TEST SETUPS USED FOR STANDARDS

Although the overriding principle of electrical safety is to de-energize equipment and place it into an electrically safe condition prior to work, there are numerous cases where companies put workers in PPE to perform tasks on energized equipment. The standards typically utilized to predict the magnitude of heat exposure and the protective ability of flame resistant (FR) fabric worn by exposed workers are based upon two unique electrode configurations in their test procedures as explained below. Heat transferred during tests with these orientations is most likely dominated by radiant heat.

4.1. NFPA 70E

First issued in 1979, NFPA 70E, Standard for Electrical Safety in the Workplace [4] covers the full range of electrical safety issues, from work practices to maintenance, special equipment requirements and installation. In the 1995 edition, arc flash hazards were first addressed with the addition of "arc flash hazard boundaries", with the equations based on arcs in open air. "Arc-in-a-box" equations were added to the 2000 edition as options to calculate a worker's potential heat energy density exposure. These equations came from results of arc flash tests with a steel box and vertical electrodes with open tips [5-6] as shown in Fig. 2. The 2004 edition added the IEEE 1584 equations below.

4.2. IEEE 1584

Issued in 2002, IEEE 1584TM-2002, Guide for Arc Flash Hazard Calculations, [7] provides guidelines for an analysis to

"identify the flash-protection boundary and the incident energy at assigned working distances throughout any position or level in the overall electrical system." The results from over 300 arc flash tests were incorporated into the low-voltage predictive equations for enclosed equipment contained within IEEE 1584. Three enclosure sizes were used in these tests, but all tests also used the vertical electrodes with open tips shown in Fig. 2.

4.3. ASTM 1959

The current edition of ASTM F1959, Standard Test Method for Determining the Arc Rating of Materials for Clothing, [8] uses a single phase opposing electrode vertical orientation. This standard test method determines the arc rating of material used in arc rated PPE. The test procedure places materials in locations surrounding the area where the open air arc is initiated. The majority of the heat transferred to the material is likely radiated from the arc. This open air arrangement from the 1980s would simulate flashovers on overhead power systems.

5. EFFECTS ON HEAT MEASUREMENTS WITH ALTERNATE TEST CONFIGURATIONS

Research performed at Ferraz Shawmut's High Power Test Laboratory has uncovered electrode configurations that project significantly more heat energy out of enclosures toward worker locations than currently predicted by the standards. To simulate components found in low-voltage electrical equipment, various setups were created for controlled testing. Heat was measured and compared with predictions of IEEE 1584 for switchgear. Results of these comparisons were published in two recent IEEE papers. [2-3] Configurations that forced the arc's plasma jets outward toward the worker produced heat measurements nearly twice those predicted by current IEEE 1584 equations when studied at typical working distances of 18 inches.

All arrangements described below are variations of an arrangement described in IEEE 1584 [7]. These test setups used a 508mm x 508mm x 508mm steel box with one side open. 3-phase arcing tests were conducted at 208V, 480 V and 600V. The gap between electrodes was 32mm and the distance between the electrodes and the back of the box was 102mm. Incident heat energy was measured with an array of 9 copper calorimeters as described in the IEEE 1584 test procedure. Photographs of the arcs were captured from video taken with a FASTCAM high-speed camera, at up to 10,000 frames per second.

Fig. 4: Barrier test configuration simulating the line side connections of top fed equipment.

The station back-up breaker was typically set at 6 cycles to limit arc duration.

5.1. Vertical Configuration

In the vertical configuration setup used in the IEEE1584 test program, the electrodes entered the box from the top. The electrode tips were open and 254 mm from the bottom of the box. This setup simulates equipment where bussing is vertical and open-ended such as a main-lugs power panel.

The arc development, similar to that described for Fig. 1, will be downward toward the bottom of the box in this case. As described in [2], there is an outward convective flow due to the thermal expansion of the gases and not magnetic forces.

Photo of the arc development is shown in Fig.3. Most tests resulted in heat measurements consistent with the predicted levels of IEEE1584.

5.2. BARRIER CONFIGURATION

In the barrier configuration, the electrodes of the vertical setup are "terminated" into a block of insulating material (barrier) as shown in Fig. 4. This setup represents conductors connected to equipment fed from the top.

With the barrier in place, the arc's downward motion is halted and plasma jets are formed along the plane of the barrier top surface (i.e. perpendicular to the plane of the electrode). [3] This significant finding is demonstrated in Fig. 5. The photo on the top shows a side view of arc development along the plane of the barrier in a setup without side panels.

The photo at the bottom shows the same test but recessed in the box. This test shows the possibility of higher convective heat transfer toward workers than the open vertical setup. The barrier configuration also ejected significantly more molten electrode material.

Chart 1 compares heat measurements with the barrier setup to standard predictions. The bottom line represents predictions of IEEE 1584 equations for

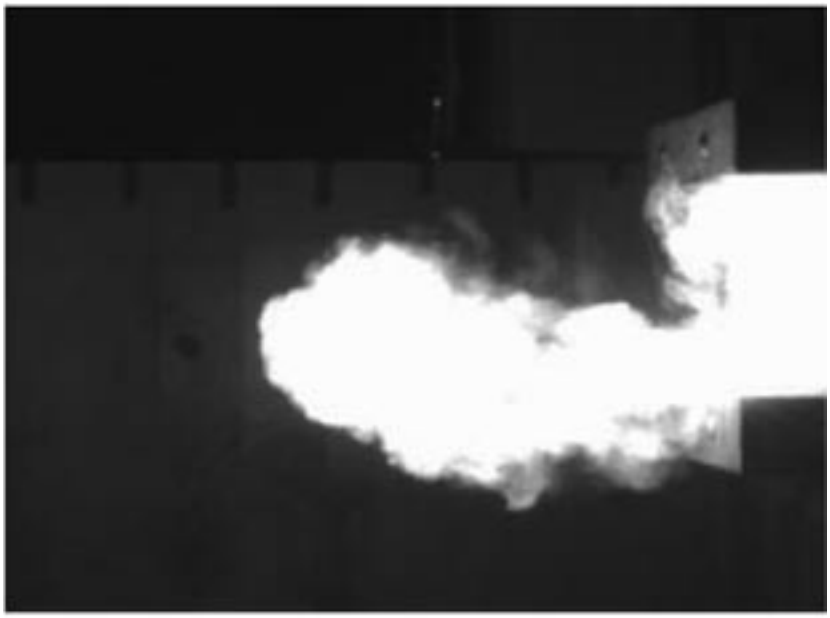


Fig. 5: Side view of arc development from barrier tests 4ms into a 42kA, 480V event. Open configuration (Top) and in a enclosure (Bottom)

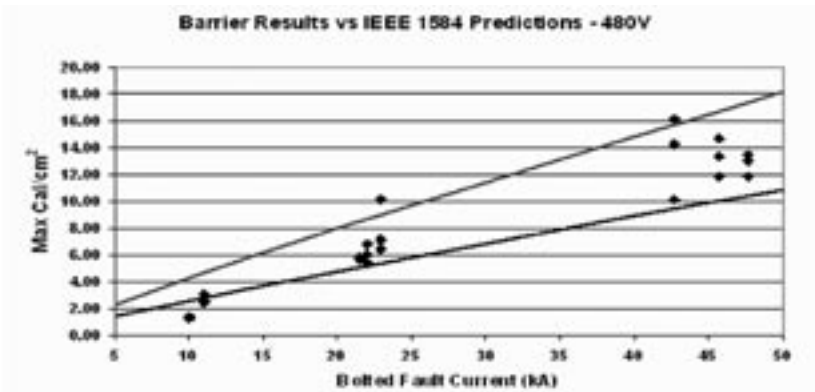


Chart I: Comparison of barrier results to predictions of IEEE 1584 equations for switchgear. The bottom line represents prediction; the top line is 167% of the prediction.

switchgear (508mm cubic box) for the available fault currents with a fixed 6-cycle clearing time.

Alarmingly, the barrier test results almost always rose above the line sometimes more than twice the prediction.

5.3. HORIZONTAL CONFIGURATION

Another configuration that deserves serious consideration is the "horizontal electrode configuration". This setup simulates equipment where bussing is open-ended, but pointing toward the front of the enclosure, like that in the equipment shown in Fig. 6.

When the electrodes are horizontal and fed from the back, the arc development is very similar to that described for Fig. 1 and is shown in Fig. 7. In the top picture of Fig 7, the electrodes were brought to the front of the box, clearly showing the plasma jets formed on the tips of the electrodes. In the bottom picture, the electrodes were moved to 104 mm from the back of the box. Although the plasma jets are not visible, there is a greater outward flow, since the walls of the enclosure give a more focused expansion of the plasma.

Like the barrier configuration, all tests resulted in heat measurements significantly above the predicted levels. In some cases, the incident heat energy density was more than three times that of the vertical tests.

Of equal concern is the fact that arcing currents were below predicted levels for this configuration (see Chart II). In some applications, clearing times will be significantly longer than expected if the arcing current is too low to operate the short circuit element of the upstream overcurrent protective device (OCPD). In these applications, the increase in arc flash heat energies will be far greater than the differences obtained in tests with a fixed clearing time of six cycles.

5.4. TESTS WITH CURRENT-LIMITING FUSES

IEEE 1584 has equations to predict incident energy from equipment when protected by UL Class RK1 fuses [9] and UL Class L fuses [10] with ampere ratings of 2000A and less. These equations were derived from 600V tests using the vertical configuration of Fig. 2 [7, 11]. Plots of the predicted incident energy for two fuses are shown in Chart III.

If the arc fault current is large enough for these fuses to be in their current-limiting ranges, the fuses will dramatically reduce the electrical energy delivered to the arc. Extensive testing has shown that Class RK1 fuses and Class L fuses of

1600A and less can limit incident energies to below the 1.2 cal/cm2 (5 J/cm2) critical value accepted for a second degree burn.

A number of tests with current-limiting fuses showed, with proper fuse selection, that workers would be exposed to far less heat energy even when standing in locations subject to the plasma flow from the alternate configurations (see Fig. 8). The heat measured during tests with all configurations was very close to that predicted by current IEEE 1584 equations. Plants currently employing this conservative method of protection will still need to recalculate arc fault currents and determine if fuses will be operating in their current-limiting modes for arc faults on equipment with horizontal electrodes.

6. EFFECTS OF ALTERNATE CONFIGURATION TESTS ON PPE

Preliminary investigations showed that many protective FR fabrics did not yield the same level of thermal protection when placed within the directional plasma flow for the barrier configuration. Tests were performed with FR fabric placed at 18 inches from the electrodes of the vertical, barrier and horizontal configurations. See Fig. 9 for the fabric test setup. A variety of currents and clearing times were used in these 480V tests to generate a range of heat energies for the tests.

There were surprising results with the barrier and horizontal tests, as some fabrics performed at only 50% of their arc ratings. Initial testing of the vertical configuration without the barrier also indicated that the arc rating of FR fabrics is reduced. It is suspected that greater heat transfer through the material because of the increased convective energy component is responsible for its decreased performance in the plasma-rich region of the arc. Equally surprising results were obtained for arc rated faceshields, which exhibited an increased arc rating. This would be expected since, unlike the permeable FR fabrics, faceshields are impermeable to the increased convective energy component.

Fig. 6: The horizontal test setup was designed to simulate rear-fed equipment like this unit.

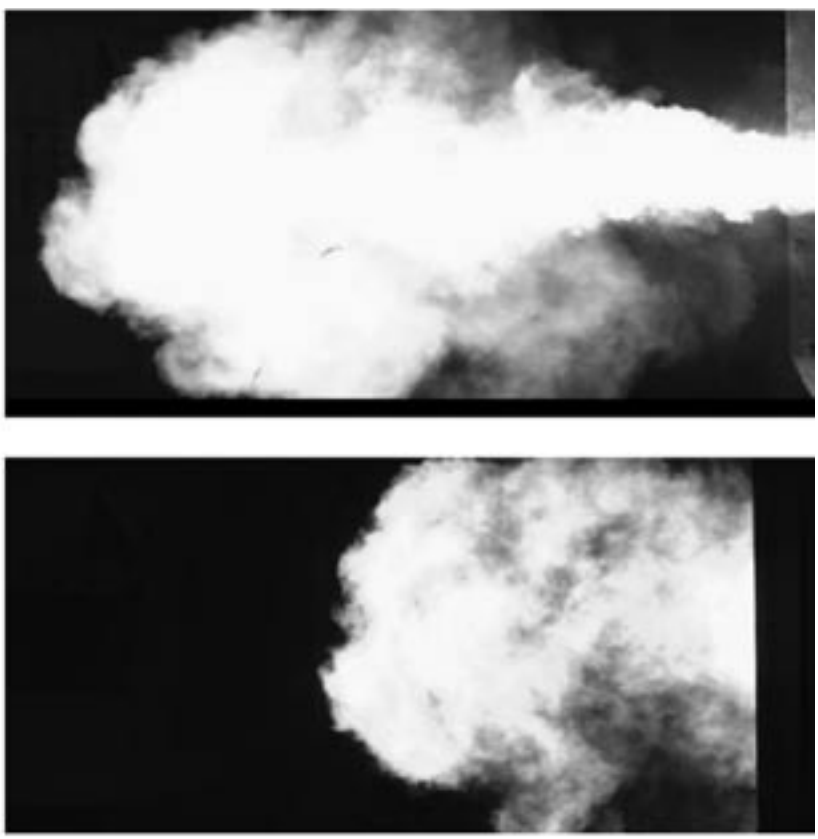


Fig. 7: Side view of plasma flow at 8 milliseconds into a 44kA 600V arcing event for horizontal electrodes. Electrode tips are flush with the front of the box and recessed to 104mm from the back of the horizontal setup test box.

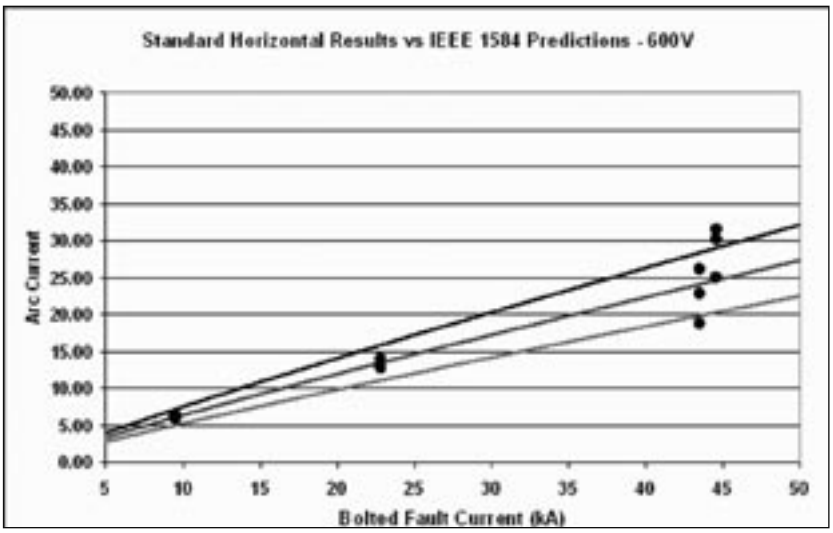


Chart II: Comparison of arc currents from horizontal tests to predictions of IEEE 1584 equations for switchgear.
Note that some of the test results were below even the 85% value recommended by the standard.

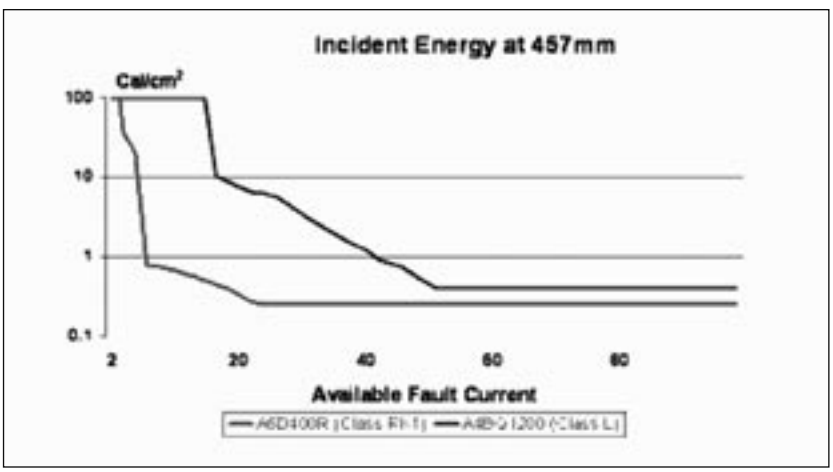


Chart III: Plot of predicted incident energies.

Fig. 8: Photo of maximum reach of plasma with current-limiting effect of 600A UL Class RK1 fuses. Test conditions are the same as those described in Fig. 7.

7. MOVING FORWARD

There are two major areas of improvement for better protection of workers against the heat of arc flash events. Both areas are related to the possibility that workers could be directly immersed in the developing plasma flow described in the foregoing text.

First, equipment configurations that would direct arc development outward need to be clearly identified and models developed to better predict the levels of heat energy that can be presented to workers from arc flashes in such equipment.

Second, the test method and a modified arc rating system for PPE need to be developed to address the reduced performance of PPE for hazards involving equipment configurations that would direct the plasma flow outward toward the worker.
Arc flash hazard analysis studies will be more important than ever. As better models of arc faults become available, users will be able to quickly update and assess situations where greater hazards will be expected.

For those who have already completed studies, it is strongly recommended that you review these studies and implement projects to mitigate the hazards wherever possible. Among other things, actions should include standardizing on UL Class J fuses and switching Class H, K and RK-5 fuses to RK-1s. Lower threshold currents provide the widest range of current-limiting operation and lowest energies. Tests with all configurations yielded results of 0.5 cal/cm2 or less when these fuses operated in their current-limiting modes.

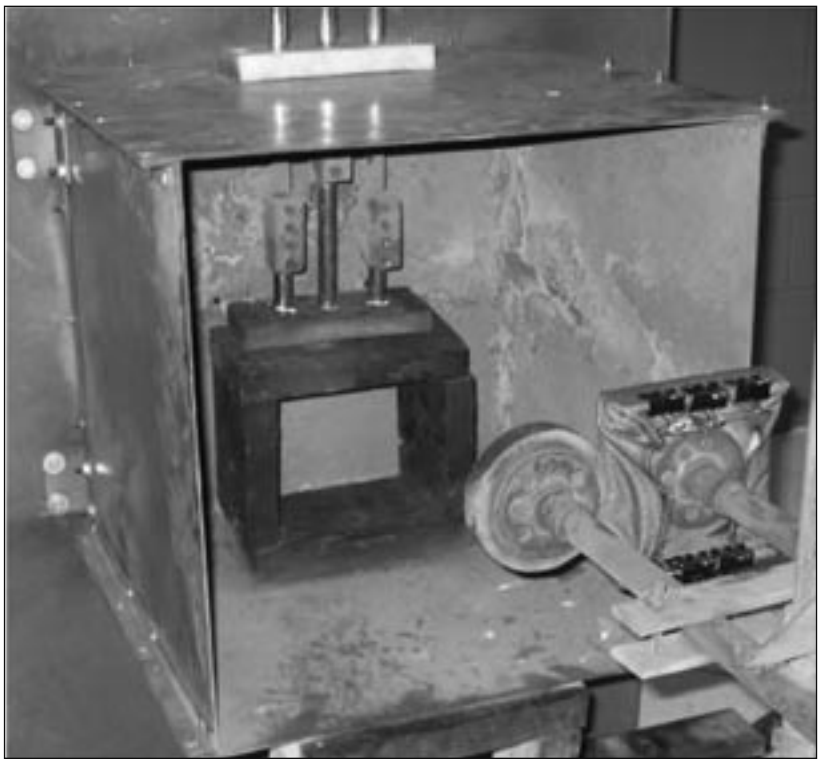
Until further testing is done, consider modifying your PPE strategy as follows. If equipment is suspected to be similar to the alternate plasma flow configurations described above, then consider the rating of protective clothing to be half the listed arc rating. When using the NFPA 70E Tables 130.7(C)(9)(A) and 130.7(C)(10) to select protective clothing and PPE, add one Hazard Risk Category (HRC) number to HRC0, HRC1, HRC2 and HRC3. For HRC4 hazards, avoid using the Tables or select PPE with a rating of at least 80 cal/cm2.

8. INDUSTRY ACTION

Leading organizations concerned with electrical safety are currently investigating the results of the research outlined in this article. The IEEE 1584 working group has joined with the NFPA 70E committee to form the IEEE/NFPA joint collaborative initiative on arc flash research. The goal of this research is to provide the information and knowledge needed to enhance safety standards that

predict the hazards of arc flash events and improve safeguards for workers. The research and test planning committee has already developed a comprehensive test protocol to further quantify these findings and investigate the many other hazards of arcing events (e.g. pressure waves, sound, toxic smoke).

Additionally, the ASTM F18.65 subcommittee on Wearing Apparel has formed a task force to further study the performance of materials in the plasma flow. The task force will identify any needed modification or additions to the test protocols of ASTM F 1959F/ F1959M-06a for material performance.



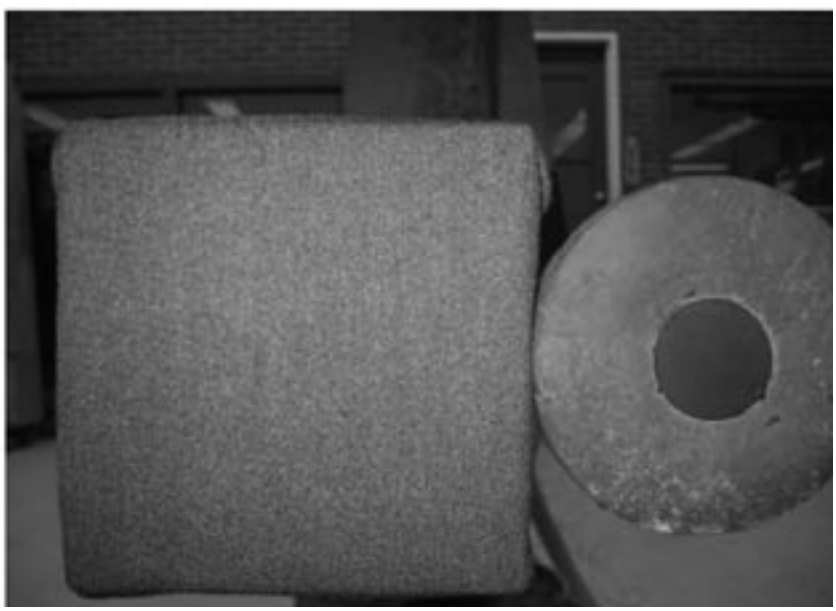


Fig. 9: (Top): Fabric test setup with barrier test. (Bottom): Front view of bare and fabric covered calorimeter.

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[9] UL 248-12 Low-Voltage Fuses - Part 12: Class R Fuses.

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[11] Doughty, R.L., Neal, T.E., Macalady, T.L., and Saporita, V. "The use of Low-Voltage Current-Limiting Fuses to Reduce Arc Flash Energy." IEEE Transaction on Industry Applications, vol 36, no 6, November-December 2000, pp 1741-1749.

Transmission and Distribution Safety

Occupational Safety & Health Administration (OSHA)

GENERAL REQUIREMENTS - §1926.950

APPLICATION

The occupational safety and health standard contained here applies to the construction of electric transmission and distribution lines and equipment. The term "construction" as used here includes the erection of new electric transmission and distribution lines and equipment, and the alteration, conversion, and improvement of existing electric transmission and distribution lines and equipment.

Existing electric transmission and distribution lines and electrical equipment need not be modified to conform to the requirements of applicable standards in this subpart, until "construction" work as described above is to be performed on such lines or equipment.

The standards set forth in this Subpart V provide minimum requirements for safety and health. Employers may require adherence to additional standards which are not in conflict with these standards. OSHA has promulgated a general industry standard to protect employees from the hazards arising out of the operation or maintenance of electric power generation, transmission and distribution installations (29 CFR 1910.269). Although this standard does not apply to construction work, the reader is encouraged to refer to it for general information, since it is provides comprehensive safe work practices.

INITIAL INSPECTIONS, TESTS, OR DETERMINATIONS

Existing conditions shall be determined by an inspection or a test before starting work. Such conditions shall include, but not be limited to, energized lines and equipment, conditions of poles, and the location of circuits and equipment, including power and communication lines, CATV and fire alarm circuits.

Electric equipment and lines shall be considered energized until determined to be de-energized by tests or other appropriate methods or means.

Operating voltage of equipment and lines shall be determined before working on or near energized parts.

CLEARANCES

No employee shall be permitted to approach or take any conductive object without an approved insulating handle closer to exposed energized parts than shown in Table V-1, unless:

- The employee is insulated or guarded from the energized part (gloves or gloves with sleeves rated for the voltage involved shall be considered insulation of the employee from the energized part), or
- The energized part is insulated or guarded from him/her and any other conductive object

TABLE V-1

Alternating Current - Minimum Distances

Voltage Range (phase to phase) Kilovolts	Minimum Working and Clear Hot Stick Distance
2.1 to 15	2 ft. 0 in.
15.1 to 35	2 ft. 4 in.
35.1 to 46	2 ft. 6 in.
46.1 to 72.5	3 ft. 0 in.
72.6 to 121	3 ft. 4 in.
138 to 145	3 ft. 6 in.
161 to 169	3 ft. 8 in.
230 to 242	5 ft. 0 in.
345 to 362	7 ft. 0 in.*
500 to 552	11 ft. 0 in.*
700 to 765	15 ft. 0 in.*

at a different potential, or

• The employee is isolated, insulated, or guarded from any other conductive object(s), as during live-line bare-hand work.

The minimum working distance and minimum clear hot stick distances stated in Table V-1 shall not be violated. The minimum clear hot stick distance is that for the use of live-line tools held by linemen when performing live-line work.

Conductor support tools, such as link sticks, strain carriers, and insulator cradles, may be used: provided, that the clear insulation is at least as long as the insulator string or the minimum distance specified in Table V-1 for the operating voltage.

* NOTE: From 345-362 kv., 500-552 kv., and 700-765 kv., the minimum working distance and the minimum clear hot stick distance may be reduced provided that such distances are not less than the shortest distance between the energized part and a grounded surface.

ITEM	STANDARD
Rubber insulating gloves	J6.6-1971
Rubber matting for use around electric apparatus	J6.7-1935 (R1971)
Rubber insulating blankets	J6.4-1971
Rubber insulating hoods	J6.2-1950 (R1971)
Rubber insulating line hose	J6.1-1950 (R1971)
Rubber insulating sleeves	J6.5-1971

DE-ENERGIZING LINES AND EQUIPMENT

When de-energizing lines and equipment operated in excess of 600 volts, and the means of disconnecting from electric energy is not visibly open or visibly locked out, the following provisions shall be complied with:

• The particular section of line or equipment to be de-energized shall be clearly identified, and it shall be isolated from all sources of voltage.

• Notification and assurance from the designated employee shall be obtained that:

- All switches and disconnectors through which electric energy may be supplied to the particular section of line or equipment to be worked have been de-energized;

- All switches and disconnectors are plainly tagged indicating that employees are at work;

- And that where design of such switches and disconnectors permits, they have been rendered inoperable.

• After all designated switches and disconnectors have been opened, rendered inoperable, and tagged, visual inspection or tests shall be conducted to insure that equipment or lines have been de-energized.

• Protective grounds shall be applied on the disconnected lines or equipment to be worked on.

• Guards or barriers shall be erected as necessary to adjacent energized lines.

• When more than one independent crew requires the same line or equipment to be de-energized, a prominent tag for each such independent crew shall be placed on the line or equipment by the designated employee in charge.

• Upon completion of work on de-energized lines or equipment, each designated employee in charge shall determine that all employees in his/her crew are clear, that protective grounds installed by his/her crew have been removed, and he/she shall report to the designated authority that all tags protecting his/her crew may be removed.

When a crew working on a line or equipment can clearly see that the means of disconnecting from electric energy are visibly open or visibly locked-out, the following provisions shall apply:

• Guards or barriers shall be erected as necessary to adjacent energized lines.

• Upon completion of work on deenergized lines or equipment, each designated employee in charge shall determine that all employees in their crew are clear, that protective grounds installed by their crew have been removed, and he/she shall report to the designated authority that all tags protecting their crew may be removed.

EMERGENCY PROCEDURES AND FIRST AID

The employer shall provide training or require that his/her employees are knowledgeable and proficient in:

• Procedures involving emergency situations, and

• First-aid fundamentals including resuscitation.

In lieu of the above requirements, the employer may comply with the provisions of §1926.50(c) regarding first-aid requirements.

NIGHT WORK

When working at night, spotlights or portable lights for emergency lighting shall be provided as needed to the perform the work safely.

WORK NEAR AND OVER WATER

When crews are engaged in work over or near water and when danger of drowning exists, suitable protection shall be provided as stated in §1926.104, or §1926.105, or §1926.106.

SANITATION FACILITIES

The requirements of §1926.51 of Subpart D of Part 1926, Occupational Health and Environmental Controls, shall be complied with for sanitation facilities.

HYDRAULIC FLUIDS

All hydraulic fluids used for the insulated sections of derrick trucks, aerial lifts, and hydraulic tools which are used on or around energized lines and equipment shall be of the insulating type. The requirements for fire resistant fluids of §1926.302(d)(1) do not apply to hydraulic tools covered by this paragraph.

TOOLS AND PROTECTIVE EQUIPMENT - §1926.951

PROTECTIVE EQUIPMENT

Rubber protective equipment shall be in accordance with the provisions of the American National Standards Institute (ANSI), ANSI J6 series, as follows:

Rubber protective equipment shall be visually inspected prior to use. In addition, an "air" test shall be performed for rubber gloves prior to use.

Protective equipment of material other than rubber shall provide equal or better electrical and mechanical protection.

Protective hats shall be in accordance with the provisions of ANSI Z89.2 - 1971, Industrial Protective Helmets for Electrical Workers, Class B, and shall be worn at the jobsite by employees who are exposed to the hazards of falling objects, electric shock, or burns.

PERSONAL CLIMBING EQUIPMENT

Body belts with straps or lanyards shall be worn to protect employees working at elevated locations on poles, towers, or other structures except where such use creates a greater hazard to the safety of the employees, in which case, other safeguards shall be employed.

Body belts and safety straps shall meet the requirements of §1926.959. In addition to being used as an employee safeguarding item, body belts with approved tool loops may be used for the purpose of holding tools. Body belts shall be free from additional metal hooks and tool loops other than those permitted in §1926.959.

Body belts and straps shall be inspected before use each day to determine that they are in safe working condition.
Life lines and lanyards shall comply with the provisions of §1926.104.

Safety lines are not intended to be subjected to shock loading and are used for emergency rescue such as lowering a person to the ground. Such safety lines shall be a minimum of 1/2-inch diameter and three or four strand first-grade manila or its equivalent in strength (2,650 lb.) and durability.

Defective ropes shall be replaced.

LADDERS

Portable metal or conductive ladders shall not be used near energized lines or equipment except as may be necessary in specialized work such as in high-voltage substations where non-conductive ladders might present a greater hazard than conductive ladders. Conductive or metal ladders shall be prominently marked as conductive and all necessary precautions shall be taken when used in specialized work.

Hook or other type ladders used in structures shall be positively secured to prevent the ladder from being accidently displaced.

LIVE-LINE TOOLS

Only live-line tool poles having a manufacturer's certification to withstand the following minimum tests shall be used:

• 100,000 volts per foot of length for 5 minutes when the tool is made of fiberglass; or

• 75,000 volts per foot of length for 3 minutes when the tool is made of wood; or

• Other tests equivalent to these tests as appropriate.

All live-line tools shall be visually inspected before use each day. Tools to be used shall be wiped clean and if any hazardous defects are indicated, removed from service.

MEASURING TAPES OR MEASURING ROPES

Measuring tapes or measuring ropes which are metal or contain conductive strands shall not be used when working on or near energized parts.

HAND TOOLS

Switches for all powered hand tools shall comply with §1926.300(d).
All portable electric hand tools shall:

• Be equipped with three-wire cord having the ground wire permanently connected to the tool frame and means for grounding the other end; or

• Be of the double insulated type and permanently labeled as "Double Insulated"; or

• Be connected to the power supply by means of an isolating transformer, or other isolated power supply.

All hydraulic tools which are used on or around energized lines or equipment shall use nonconducting hoses having adequate strength for the normal operating pressures. It should be noted that the provisions of §1926.302(d)(2) shall also apply.

All pneumatic tools which are used on or around energized lines or equipment shall:

• Have nonconducting hoses having adequate strength for the normal operating pressures, and

• Have an accumulator on the compressor to collect moisture.

MECHANICAL EQUIPMENT - §1926.952

GENERAL

Visual inspections of the equipment shall be made to determine that it is in good condition each day the equipment

is to be used.

Tests shall be made at the beginning of each shift during which the equipment is to be used to determine that the brakes and operating systems are in proper working condition.

No employer shall use any motor vehicle equipment having an obstructed view to the rear unless:

• The vehicle had a reverse signal alarm audible above the surrounding noise level, or

• The vehicle is backed up only when an observer signals that it is safe to do so.

AERIAL LIFTS

The provisions of §1926.556 shall apply to the utilization of aerial lifts.

When working near energized lines or equipment, aerial lift trucks shall be grounded or barricaded and considered as energized equipment, or the aerial lift truck shall be insulated for the work being performed.

Equipment or material shall not be passed between a pole or structure and an aerial lift while an employee working from the basket is within reaching distance of energized conductors or equipment that are not covered with insulating protective equipment.

DERRICK TRUCKS, CRANES AND OTHER LIFTING EQUIPMENT

All derrick trucks, cranes and other lifting equipment shall comply with Subparts N and O of Part 1926 except:

• As stated in §1926.550(a)(15)(i) and (ii) relating to clearance (for clearances in this subpart see Table V-1), and

• Derrick truck (electric line trucks) shall not be required to comply with §1926.550(a)(7)(vi), (a)(17), (b)(2), and (e).

With the exception of equipment certified for work on the proper voltage, mechanical equipment shall not be operated closer to any energized line or equipment than the clearances set forth in §1926.950(c) unless:

• An insulated barrier is installed between the energized part and the mechanical equipment, or

• The mechanical equipment is grounded, or

• The mechanical equipment is insulated, or

• The mechanical equipment is considered as energized.

MATERIAL HANDLING - §1926.953

UNLOADING

Prior to unloading steel, poles, cross arms and similar material, the load shall be thoroughly examined to ascertain if the load has shifted, binders or stakes have broken or the load is otherwise hazardous to employees.

POLE HAULING

During pole hauling operations, all loads shall be secured to prevent displacement and a red flag shall be displayed at the trailing end of the longest pole.

Precautions shall be exercised to prevent blocking of roadways or endangering other traffic.

When hauling poles during the hours of darkness, illuminated warning devices shall be attached to the trailing end of the longest pole.

STORAGE

No materials or equipment shall be stored under energized bus, energized lines, or near energized equipment, if it is practical to store them elsewhere.

When materials or equipment are stored under energized lines or near energized equipment, applicable clearances shall be maintained as stated in Table V-1; and extraordinary caution shall be exercised when moving materials near such energized equipment.

TAG LINE

Where hazards to employees exist, tag lines or other suitable devices shall be used to control loads being handled by hoisting equipment.

OIL FILLED EQUIPMENT

During construction or repair of oil filled equipment, the oil may be stored in temporary containers other than those required in §1926.152, such as pillow tanks.

FRAMING

During framing operations, employees shall not work under a pole or a structure suspended by a crane, A-frame or similar equipment unless the pole or structure is adequately supported.

ATTACHING THE LOAD

The hoist rope shall not be wrapped around the load. This provision shall not apply to electric construction crews when setting or removing poles.

GROUNDING FOR PROTECTION OF EMPLOYEES - §1926.954

GENERAL

All conductors and equipment shall be treated as energized until tested or otherwise determined to be deenergized or until grounded.

NEW CONSTRUCTION

New lines or equipment may be considered deenergized and worked as such where:

• The lines or equipment are grounded, or

• The hazard of induced voltages is not present, and adequate clearances or other means are implemented to prevent contact with energized lines or equipment and the new lines or equipment.

COMMUNICATION CONDUCTORS

Bare wire communication conductors on power poles or structures shall be treated as energized lines unless protected by insulating materials.

VOLTAGE TESTING

De-energized conductors and equipment which are to be grounded shall be tested for voltage. The results of this test shall determine the subsequent procedures as required in §1926.950(d).

ATTACHING GROUNDS

When attaching grounds, the ground end shall be attached first, and the other end shall be attached and removed by means of insulated tools or other suitable devices.

When removing grounds, the grounding device shall first be removed from the line or equipment using insulating tools or other suitable devices.

GROUNDS PLACEMENT

Grounds shall be placed between the work location and all sources of energy and as close as practicable to the work location, or grounds shall be placed at the work location. If work is to be performed at more than one location in a line section, the line section must be grounded and short circuited at one location in the line section and the conductor to worked on shall be grounded at each work location. The minimum distance shown in Table V-1 shall be maintained from ungrounded conductors at the work location. Where the making of a ground is impracticable, or the conditions resulting would be more hazardous than working on the lines or equipment without grounding, the grounds may be omitted and the line or equipment worked as energized.

TESTING WITHOUT GROUNDS

Grounds may be temporarily removed only when necessary for test purposes and extreme caution shall be exercised during the test procedures.

GROUNDING ELECTRODE

When grounding electrodes are utilized, such electrodes shall have a resistance to ground low enough to remove the danger of harm to personnel or permit prompt operation of protective devices.

GROUNDING TO TOWER

Grounding to tower shall be made with a tower clamp capable of conducting the anticipated fault current.

GROUND LEAD

A ground lead, to be attached to either a tower ground or driven ground, shall be capable of conducting the anticipated fault current and have a minimum conductance of No. 2 AWG copper.

OVERHEAD LINES - §1926.955

WHEN WORKING ON OR WITH OVERHEAD LINES, THE FOLLOWING PROVISIONS SHALL BE COMPLIED WITH:

• Prior to climbing poles, ladders, scaffolds, or other elevated structures, an inspection shall be made to determine that the structures are capable of sustaining the additional or unbalanced stresses to which they will be subjected.

• Where poles or structures may be unsafe for climbing, they shall not be climbed until made safe by guying, bracing, or other adequate means.

• Before installing or removing wire or cable, strains to which poles and structures will be subjected shall be considered and necessary action taken to prevent failure of supporting structures.

• When setting, moving, or removing poles using cranes, derricks, gin poles, A-frames, or other mechanized equipment near energized lines or equipment, precautions shall be taken to avoid contact with energized lines or equipment, except in bare-hand live-line work, or where barriers or protective devices are used.

• Equipment and machinery operating adjacent to energized lines or equipment shall comply with §1926.952(c)(2).

• Unless using suitable protective equipment for the voltage involved, employees standing on the ground shall avoid contacting equipment or machinery working adjacent to energized lines or equipment.

• Lifting equipment shall be bonded to an effective ground or it shall be considered energized and barricaded when utilized near energized equipment or lines.

• Pole holes shall not be left unattended or unguarded in areas where employees are currently working.

• Tag lines shall be of a non-conductive type when used near energized lines.

This section (§1926.955) also contains requirements for metal tower construction, stringing or removing de-energized conductors, stringing adjacent to energized lines, and live-line bare-hand work.

UNDERGROUND LINES - §1926.956

GUARDING AND VENTILATING STREET OPENING USED FOR ACCESS TO UNDERGROUND LINES OR EQUIPMENT

Appropriate warning signs shall be promptly placed when covers of manholes, handholes, or vaults are removed. The nature and location of the hazards involved determine what is an appropriate warning sign.

Before an employee enters a street opening, such as a manhole or an unvented vault, it shall be promptly protected with a barrier, temporary cover, or other suitable guard.

When work is to be performed in a manhole or unvented vault:

• No entry shall be permitted unless forced ventilation is provided or the atmosphere is found to be safe by testing for oxygen deficiency and the presence of explosive gases or fumes;

• Where unsafe conditions are detected, by testing or other means, the work area shall be ventilated and otherwise made safe before entry;

• Provisions shall be made for an adequate continuous supply of air.

WORK IN MANHOLES

While work is being performed in manholes, an employee shall be available in the immediate vicinity to render emergency assistance as may be required. This shall not preclude the employee in the immediate vicinity from occasionally entering a manhole to provide assistance, other than an emergency. This requirement does not preclude a qualified employee, working alone, from entering for brief periods of time, a manhole where energized cables or equip-

ment are in service, for the purpose of inspection, housekeeping, taking readings, or similar work if such work can be performed safely.

When open flames must be used or smoking is permitted in manholes, extra precautions shall be taken to provide adequate ventilation.

Before using open flames in a manhole or excavation in an area where combustible gases or liquids may be present, such as near a gasoline service station, the atmosphere of the manhole or excavation shall be tested and found safe or cleared of the combustible gases or liquids.

TRENCHING AND EXCAVATING

- During excavation or trenching, in order to prevent the exposure of employees to the hazards created by damage to dangerous underground facilities, efforts shall be made to determine the location of such facilities and work conducted in a manner designed to avoid damage.
- Trenching and excavation operations shall comply with §1926.651 and §1926.652.
- When underground facilities are exposed (electric, gas, water, telephone, etc.) they shall be protected as necessary to avoid damage.
- Where multiple cables exist in an excavation, cables other than the one being worked on shall be protected as necessary.
- When multiple cables exist in an excavation, the cable to be worked on shall be identified by electrical means unless its identity is obvious by reason of distinctive appearance.
- Before cutting into a cable or opening a splice, the cable shall be identified and verified to be the proper cable.
- When working on buried cable or on cable in manholes, metallic sheath continuity shall be maintained by bonding across the opening or by equivalent means.

CONSTRUCTION IN ENERGIZED SUBSTATIONS - §1926.957

WORK NEAR ENERGIZED EQUIPMENT

FACILITIES

When construction work is performed in an energized substation, authorization shall be obtained from the designated, authorized person before work is started, and the following shall be determined:

- What facilities are energized, and
- What protective equipment and precautions are necessary for the safety of personnel.

Extraordinary caution shall be exercised in the handling of busbars, tower steel, materials, and equipment in the vicinity of energized facilities. The requirements set forth in §1926.950(c) shall be complied with.

DE-ENERGIZED EQUIPMENT OR LINES

When it is necessary to de-energize equipment or lines for protection of employees, the requirements of §1926.950(d) shall be complied with.

BARRICADES AND BARRIERS

Barricades or barriers shall be installed to prevent accidental contact with energized lines or equipment.

Where appropriate, signs indicating the hazard shall be posted near the barricade or barrier. These signs shall comply with §1926.200.

CONTROL PANELS

Work on or adjacent to energized control panels shall be performed by designated employees.

Precaution shall be taken to prevent accidental operation of relays or other protective devices due to jarring, vibration, or improper wiring.

MECHANICAL EQUIPMENT

Use of vehicles, gin poles, cranes, and other equipment in restricted or hazardous areas shall at all times be controlled by designated employees.

All mobile cranes and derricks shall be effectively grounded when being moved or operated in close proximity to energized lines or equipment, or the equipment shall be considered energized. Fenders shall not be required for lowboys used for transporting large electrical equipment, transformers, or breakers.

STORAGE

The storage requirements of §1926.953(c) shall be complied with.

SUBSTATION FENCES

When a substation fence must be expanded or removed for construction purposes, a temporary fence affording similar protection when the site is unattended, shall be provided. Adequate interconnection with ground shall be maintained between temporary fence and permanent fence.

All gates to all unattended substations shall be locked, except when work is in progress.

FOOTING EXCAVATION

Excavation for auger, pad and piling type footings for structures and towers shall require the same precautions as for metal tower construction [see §1926.955(b)(1)].

No employee shall be permitted to enter an unsupported auger-type excavation in unstable material for any purpose. Necessary clean-out in such cases shall be accomplished without entry.

Arc Flash Safety Solutions

Courtesy of Eaton

BREAKERS VS. FUSES

With today's increasing focus on arc flash safety, the issue of whether to use breakers or fuses arises frequently. Many times the focus is on calculating the arc flash hazard at the maximum current available from the circuit; however, doing the calculations only at these levels provides just part of the story.

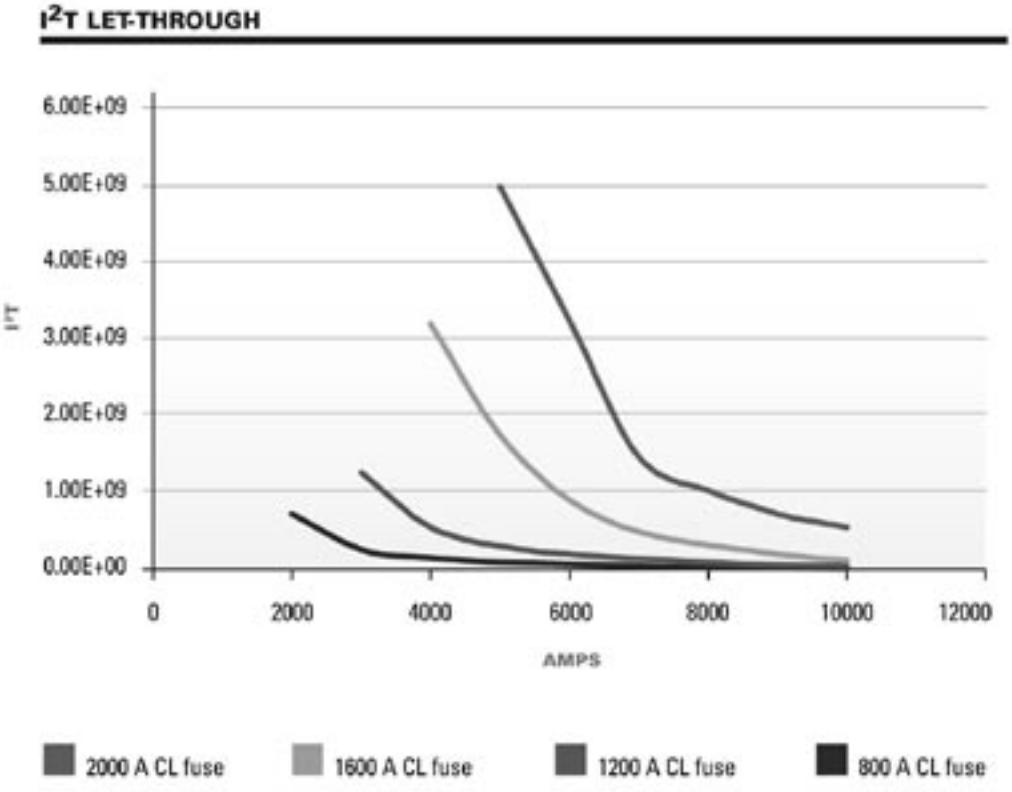
Performing the arc flash Hazard Risk Category (HRC) calculations only at bolted fault magnitudes will result in a misleading and dangerous underestimate of the HRC on a circuit protected by fuses. This is because the worst case HRC for current limiting fuse-protected circuits will not be found at bolted fault levels, but rather at any magnitude below this point. A current-limiting fuse performs best at the highest current levels. At levels below bolted fault, the fuse allows progressively higher energy let-through values.

Good engineering design requires determination of the HRC for the worst-case current magnitude. HRC is a function of let-through energy, and mathematically, the let-through energy is proportional to the magnitude of the current squared times the time it flows.

When using breakers, current flowing in excess of the instantaneous setting must, by definition, results in an instantaneous trip. On the contrary, a fuse clearing time increases very rapidly as the current decreases.

When you multiply these two effects together, something interesting happens as the fault current decreases. The energy let-through due to the current is reduced by the square, but the time is increasing by a value proportional to the current raised to a power higher than two.

The take away for the engineer doing the arc flash calculations is that if the time increases faster than the square of the current (which occurs for all current limiting fuses), the arc flash hazard for these fuse protected circuits increases as the current decreases, a non-intuitive conclusion. The engineer must determine the magnitude of this maximum energy let-through in order to properly assign a Hazard Risk Category. Note that for a breaker or MCP protected circuit, in all cases the energy let-through decreases as the fault current decreases as long as the current remains above the instantaneous pickup point of the breaker.



Notice that as the magnitude of arcing current decreases, the I^2t let-through increases, causing a corresponding increase in the arc flash hazard. For a breaker-protected circuit, the arc flash hazard decreases for decreased arcing currents. Regardless of whether fuses or breakers are used, a prudent arc flash hazard study must account for the worst case and the worst case for fuses is not at the bolted fault levels.

Most engineers test their breakers regularly, but it's important that they also regularly test and re-certify the fuse elements.

Fuse characteristics change over time. Fuse elements are constructed of materials that are not chemically inert. Gas tight fittings to limit environmental incursions are used, but there is no such thing as a perfect gas tight fitting. And of course there is the issue of stress on fuses. For example, recall that all three fuses on a faulted 3-phase circuit must be replaced should any individual fuse blow. The remaining unopened fuses have been altered in a way not obvious without re-testing. But how do you know that a fault didn't occur just below the fuse melting point causing a weakening of the element but not blowing the fuse? Several publicly available case studies document fuse aging as the likely cause of system coordination problems.

Effect of Insulating Barriers in Arc Flash Testing

By Robert Wilkins, Mike Lang, and Malcolm Allison, IEEE

I. INTRODUCTION

The IEEE 1584TM-2002 standard for arc flash analysis [1] uses calculation methods for the determination of arcing currents and incident energy density which are based on the results of test data obtained with 3-phase arcing electrodes arranged in a vertical plane, and with open electrode tips pointing downwards. The calorimeters used to measure incident energy density were mounted at right angles to this plane. Most of the tests were done in metal boxes with no front cover to represent equipment with the door open.

Stokes and Sweeting [2] have criticized the use of this arrangement on the basis that the calorimeters, being "off axis", will mainly pick up radiated energy from the arcs, and that this does not represent the worst case. Their test setups used long horizontal electrodes in open air, pointing away from the supply and directed at the calorimeters. Very high values of incident energy density were produced by an expanding plasma cloud driven towards the calorimeters by magnetic forces and plasma jets.

In a paper by the authors [3], the effect of electrode orientation was investigated using a metal box and calorimeters conforming to the IEEE 1584 standard arrangement. Various electrode configurations were used, and the results confirmed Stokes and Sweeting's findings that the horizontal case is more severe, producing incident energies about three times higher than with vertical electrodes.

Despite this, there is still no clear consensus in industry that the vertical test arrangement should be replaced by a horizontal arrangement, because it is felt that the horizontal arrangement is not representative of much equipment found in the field in North America.

Both the vertical and horizontal arrangements tested previously used conductor tips which terminated in open air.

This is not a situation that is found in real equipment, in which the conductors usually enter the terminal block of some device.

This article describes arcing fault testing done in a high-power test laboratory with vertical conductors in a box, but with the electrodes terminating in an insulating barrier or components such as power distribution blocks or fuse holders. This configuration is believed to be more representative of the majority of low-voltage equipment in industrial control panels and MCCs.

The results show that with vertical electrodes and an insulating barrier, a strong horizontal outward plasma flow is produced, which gives higher incident energies than obtained without the barrier. The nature of the flow is

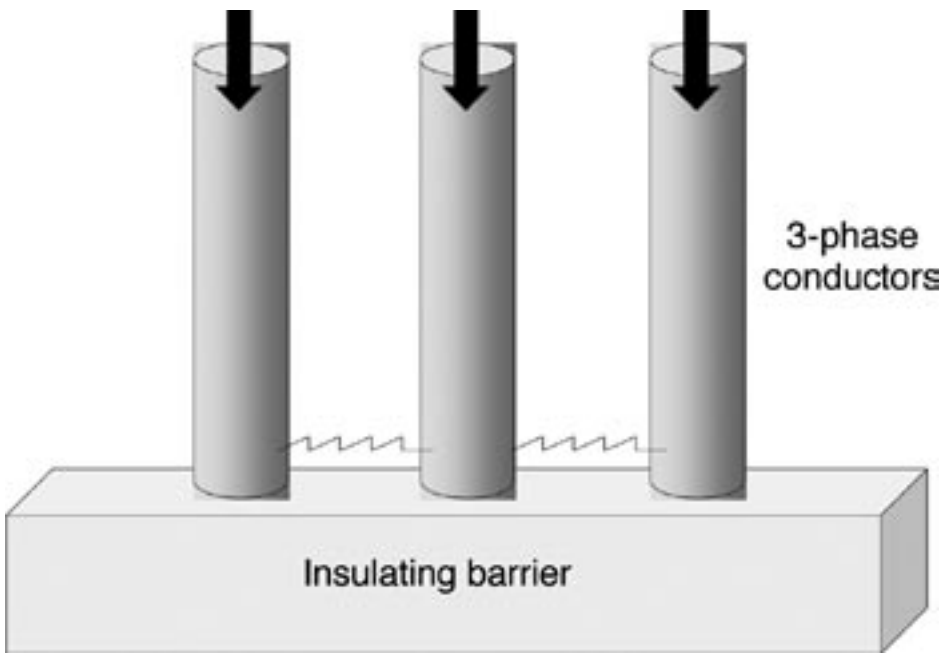


Fig. 1 Test Electrodes Terminated with Insulating Barrier

similar to that previously observed with horizontal electrodes.

The effects of the insulating barrier on arc sustainability at 208V and electrode erosion, and the influence of source X/R, are also described.

II. EFFECT OF AN INSULATING BARRIER

The test arrangement with an insulating barrier is illustrated in Fig. 1. Arcing was initiated above the barrier by a copper wire as shown. The testing was carried out as described in [3], and included the use of high-speed videography.

The barrier used was a 200mm x 27mm x 51mm block of glass-reinforced melamine, selected for its ability to withstand the very high electromagnetic forces.

When vertical electrodes are used, magnetic forces cause the arcs to be driven downwards and burn from the electrode tips. If the tips are in open air, plasma jets are formed on the tips, which cause the arcs to be driven further downwards and hit the bottom of the box.

If arcing persists, the whole box eventually fills with a plasma cloud, and "spills out" externally [3]. However, with the barrier present, the downward motion of the arcs is arrested, and arcing tends to be somewhat more stable across the surface of the barrier, which produces a noticeable increase in the erosion of the electrodes.

The following sections give results from 235 tests, at 208V, 250V, 480V and 600V, with vertical electrode spacings of 12.7mm, 32mm and 50.8mm and bolted fault currents near to 4.5kA, 10kA, 22kA and 45kA (the precise levels being dependent on the circuits available in the high-power test laboratory). 144 of these tests used an insulating barrier, while no barrier was used in the remainder. 45 tests were done with a low source X/R (<2), while the rest used a high X/R (>9). The calorimeters were located at a distance of 457mm (18") from the electrode tips.

The mean arcing current was calculated as the mean of the r.m.s. values in the three phases (which vary significantly [3]).

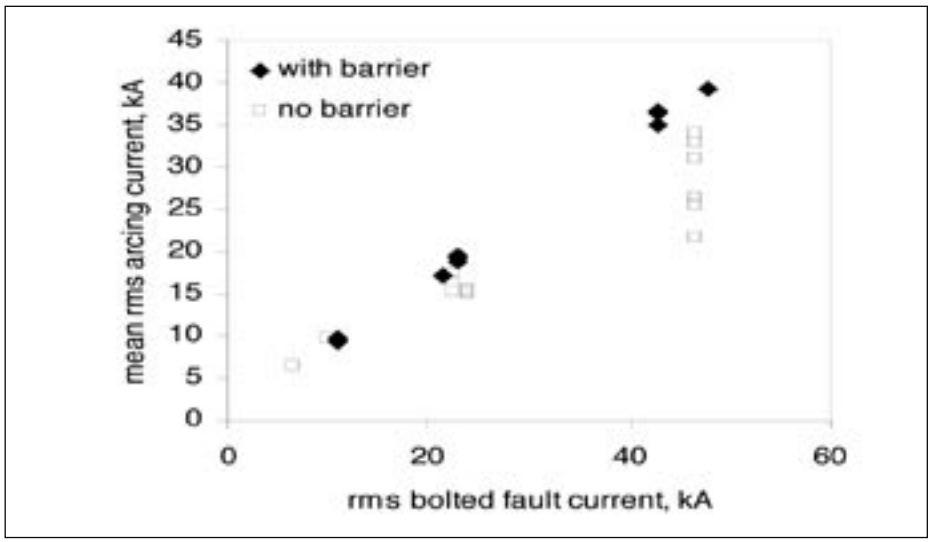


Fig. 2 Effect of Barrier on Mean Arcing Current

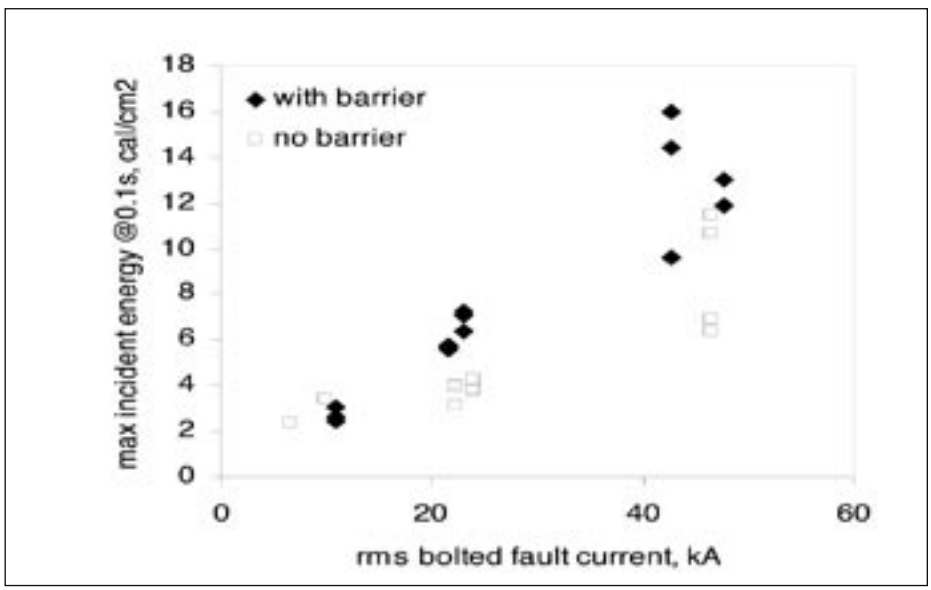


Fig. 3 Effect of Barrier on Incident Energy Density

In 205 tests, arcing was sustained and the circuit was cleared by the test station back-up circuit breaker, which was set to open after 6 cycles (0.1s). (The actual opening times varied slightly from the setting, so the incident energy measured by the calorimeters was corrected to a standard time of 0.1s).

For the other 30 tests, the arcs were self-extinguishing. This only ever occurred with test voltages of 208V and 250V.

Multiple regression analysis of results from all the tests showed that the mean arcing current was increased by about 20% when the barrier was present. The violent chaotic behavior of the high-current arcs results in considerable scatter in the data, particularly at the 45kA level.

Nevertheless, the effect of the barrier can be clearly seen in Fig. 2, which shows a comparison of mean arcing currents with and without the barrier at 480V with an arcing gap of 32mm.

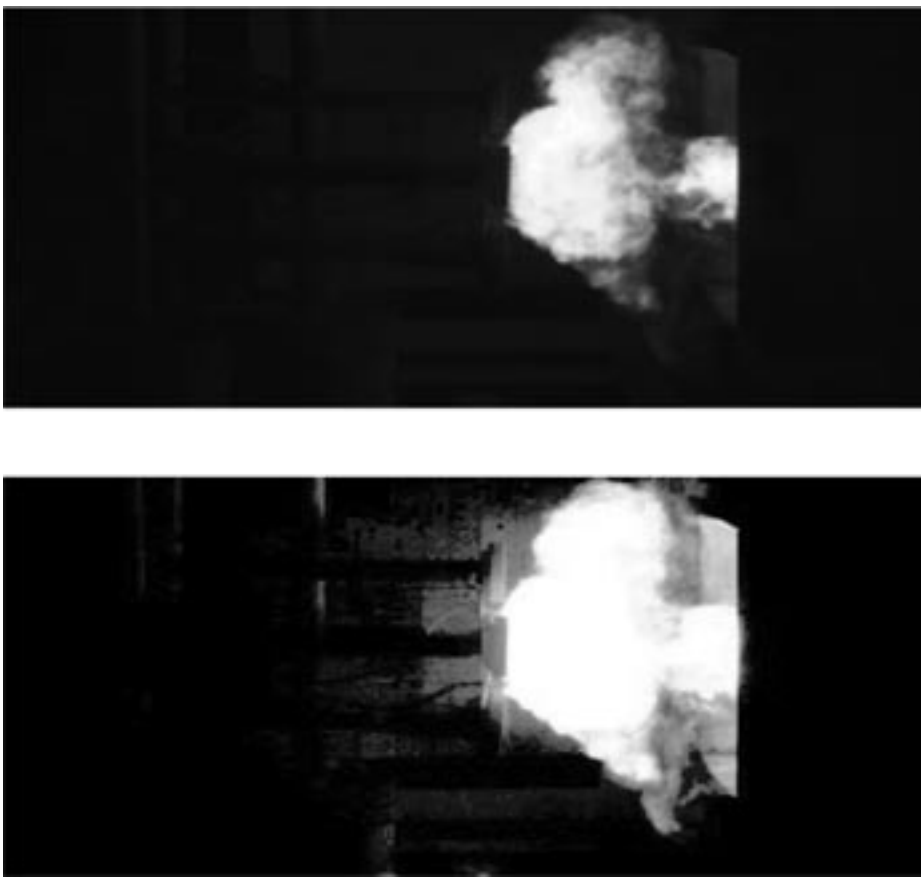


Fig. 4 Plasma Development With Insulating Barrier

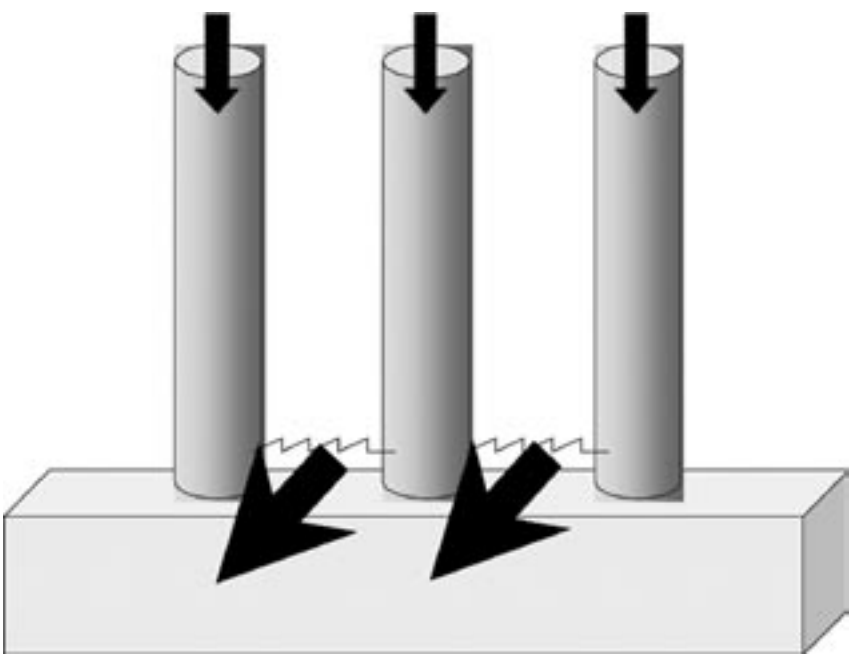


Fig. 5 Outward Deflection of Plasma by Barrier

Using Fisher's method [3,5], it can be shown that a 20% increase of arcing current at 480V means that, on average, the mean arc voltage with the barrier is about 74% of the value with no barrier. It appears that the stabilizing effect of the barrier causes the mean arc lengths to be lower, which causes the reduction in arc voltage.

For all tests, the maximum incident energy was increased by 31% with the barrier present. However, the barrier effect was increased at the higher test voltages. For all the 480V tests, the average increase was 49% and for the 600V tests the increase was 86%.

This is illustrated in Fig. 3, which shows the maximum incident energy density at a distance of 457mm (18"), as a function of bolted fault current, for tests at 480V with a 32mm gap.

Part of this increase is accounted for by the higher arcing current when the barrier is present, but a different mode of plasma development was also observed, as shown in Fig. 4.

Fig. 4 shows the plasma cloud external to the box, about 3ms after arc initiation, with a barrier present. The upper picture is a normal image frame from the high-speed camera record. The same picture is repeated in the lower image, but with the contrast greatly increased, so that the box interior and calorimeters are visible.

A strong horizontal flow has developed, and the picture looks very similar to those seen previously with horizontal electrode tests [3].

With the barrier in position, the plasma jets, which produce the plasma cloud, cannot easily develop in a downward direction, and so appear to develop in directions at right angles to the vertical plane, as illustrated in Fig. 5.

The difference in the mode of arcing was also evident in the distribution of temperature rises across the array of calorimeters. For vertical tests without a barrier, the bottom row of calorimeters was always hottest, and the temperature rise on the hottest calorimeter was 32%

higher than the mean (average for all tests).

By contrast, with the barrier present, the calorimeter in the middle of the group was always the hottest, and its temperature rise was 52% higher than the mean. This is an indication of the focusing effect, which can be clearly seen in Fig. 4.

With the barrier, the plasma flow is augmented by gas flow generated by pyrolysis of the organic material, which increases the total enthalpy and adds to the toxicity of the smoke generated, depending upon the chemical composition of the barrier material.

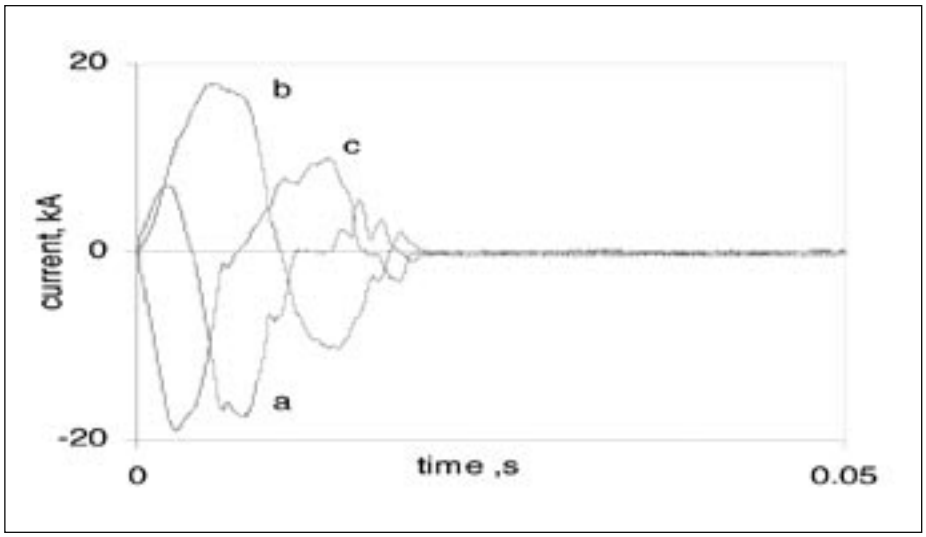


Fig. 6 Arcing Currents at 250V, 13kA - No Barrier

III. ARC SUSTAINABILITY AT 208V WITH HIGH X/R

A. WITHOUT BARRIER

Sustained arcing faults are more difficult to obtain at lower voltages. In the IEEE 1584 test dataset only one test was listed which gave sustained arcing at 208V [1].

The authors conducted arcing fault tests at 208V and 250V with arcing gaps of 12.7mm, 32mm and 50.8mm. At 208V arcing could not be sustained at 10kA or less, even with the shortest (12.7mm) gap.

Fig. 6 shows the three phase arcing currents for a typical case where the arcs self-extinguished after about 21ms, with a 12.7mm gap at 250V, 13kA. Fig. 7 shows the corresponding line-line voltages (not the arc voltages, which cannot be individually measured).

Note that even if arcing is not sustained indefinitely, some arc energy is released, and although incident energies are usually low, there is still a potential hazard.

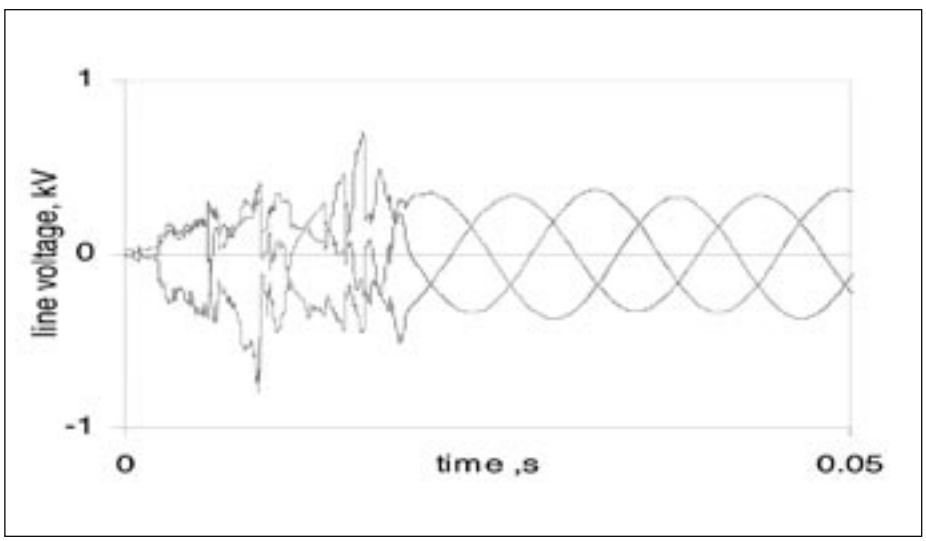


Fig. 7. Line-line Voltages at 250V, 13kA - No Barrier

B. WITH BARRIER

The shorter arc lengths and stabilizing effect with the insulating barrier make it easier for arcing to be sustained, and it was found possible to produce self-sustaining arcs at 208V. With a gap of 12.7mm, sustained arcing was obtained at 4.5kA, 10kA and 22kA. When the gap

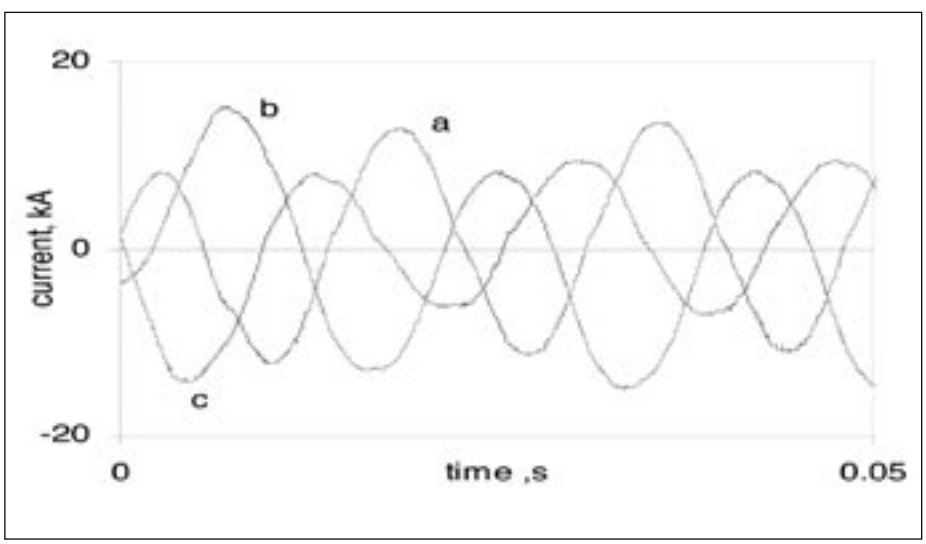


Fig. 8 Arcing Currents at 208V, 9.9kA - With Barrier

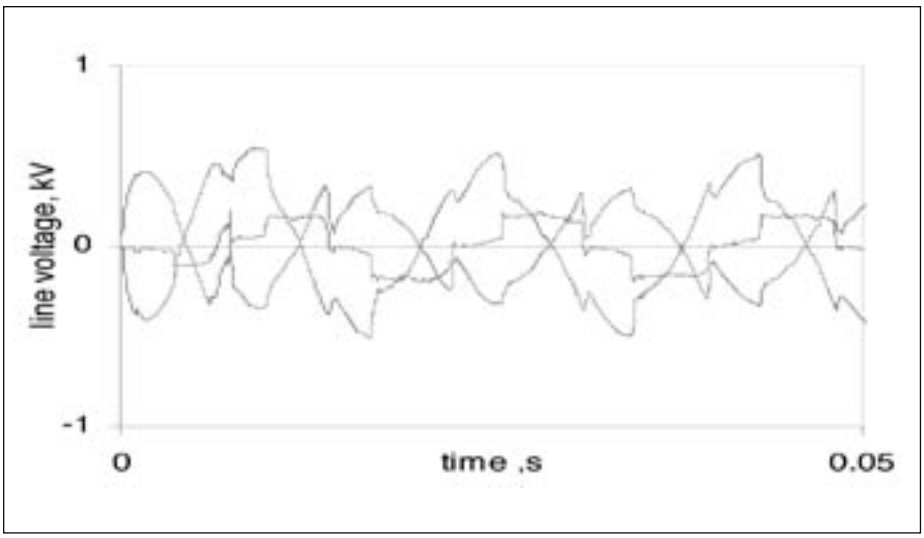


Fig. 9. Line-line Voltages at 208V, 9.9kA - With Barrier

Fig. 10 (a) Arc Initiation

Fig. 10 (b) after 6ms

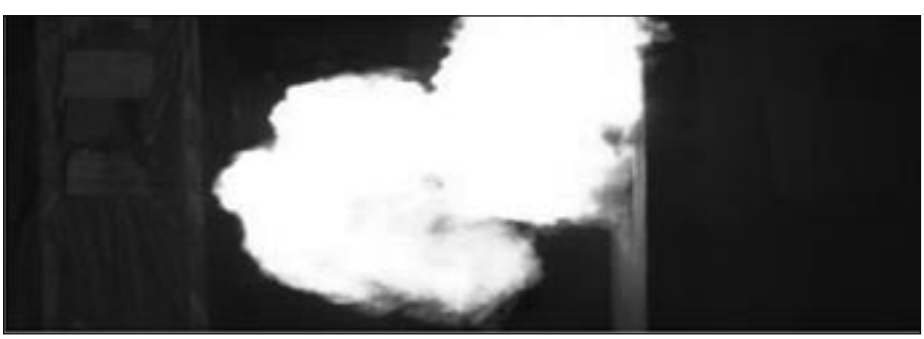


Fig. 10 (c) after 12ms

was increased to 32mm, the arcs were self-extinguishing at 4.5kA, but sustained arcs were obtained at 10kA and 22kA. For the 12.7mm gap, incident energies at 0.1s up to 2.7 cal/cm2 were measured, while for the 32mm gap this increased to 3.2 cal/cm2.

Fig. 8 shows sustained arcing currents at 208V with a bolted-fault current of 9.9kA and a 12.7mm gap. The unbalance between the phases is very marked, but arcing was sustained until the test station breaker opened the circuit after about 0.1s.

Fig. 9 shows the corresponding line-line voltages.

IV. LINE-SIDE ARCING EFFECTS

A further series of tests was carried out using real industrial components (power distribution block, fuseholder, IP20 fingersafe device) instead of the insulating barrier. In each case, the device was mounted on a vertical plate and the lineside conductors from the test source were connected into the device from the top, and the conductor sizes used were those corresponding to the ampere rating of the device. A 3-phase arcing fault was triggered in the usual way at the top of the device (on the line side).

In each case, it was found that the presence of the component below the arc roots impeded the downward development of the plasma cloud, in a similar way to that seen previously with the insulating barrier.

Figs. 10(a)-(c) show the development of arcing above a 100A power distribution block. There is some downward flow, (which depends on the physical size of the component), but also a significant horizontal outward component, so that the total flow in the case shown is directed at an angle of about 45 degrees downwards.

In Figs. 10(b) and 10(c) melting of the conductors feeding the component can be seen, which results in additional arcing in that zone.

V. ELECTRODE EROSION

It was noticed that if an insulating barrier was used with the IEEE 1584 electrodes, the erosion of the copper electrode tips was significantly higher.

To quantify this effect, some of the tests used detachable electrode tips that were weighed before and after testing to determine the amount of copper lost from the electrodes.

The rate of material loss from arcing contacts is commonly found to depend upon the arcing current raised a power X, where 1 < X < 2. This was found also to be true for the highcurrent 3-phase arcing fault, so the erosion rate can be approximated by

$$dw/dt = K\, I_{ARC}^{X} \qquad (1)$$

The erosion rates and currents for each phase were measured separately. Multiple regression on 114 such measurements gave X = 1.31.

The effect of the barrier was to increase the average erosion rate by 66%. The stabilizing effect of the barrier causes a higher proportion of the arc column power to be transferred to the electrodes. Fig. 11 shows measured erosion rates for the middle phase electrode 'B' with a 32mm gap, with and without the barrier present. The lines shown are for values of K that give the best fit to (1).

Fig. 12 shows the erosion rates measured for a 12.7mm gap with barrier present. The value of K is higher than found for the 32mm gap, presumably because a higher proportion of the total arc power is transferred to the electrodes when the gap is shorter. Similarly, tests with a 50.8mm gap gave lower erosion rates.

It was noticed that the erosion rates were noticeably less for the two outer phases, 'A' and 'C', and that there was no significant difference in the values of K for the outer phases.

There is a higher probability of multiple arc roots terminating on the middle

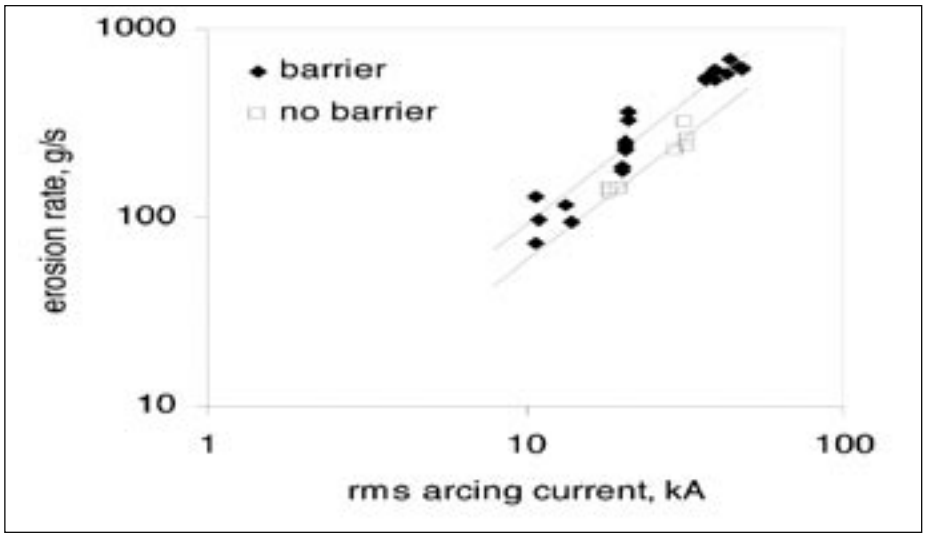


Fig. 11 Erosion Rate for Middle Phase B, 32mm gap

TABLE I

Erosion constant *K* for sustained arcing

gap	Barrier present	Outer phases 'A' & 'C'	Middle phase 'B'
12.7 mm	✓	4.82	5.61
32 mm	✓	3.87	4.41
50.8 mm	✓	3.68	4.06
32 mm	x	2.56	2.89

(The values of *K* in Table I apply with *dw/dt* in g/s and I_{ARC} in kA).

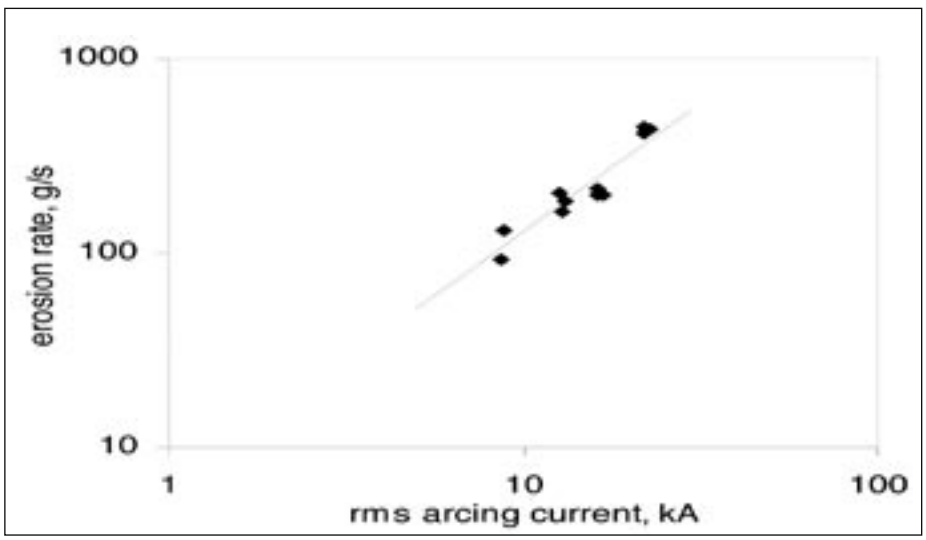


Fig. 12 Erosion Rate for Middle Phase B, 12.7mm gap

electrode, which could explain this effect.

Table I summarizes the values of the erosion constant K which gave the best fit to (1) using X =1.31.

VI. EFFECT OF SOURCE X/R

Most of the results in the IEEE 1584 test dataset were obtained with a relatively high source X/R [1]. This is typical of the way tests are carried out on high-power interrupting devices, to represent worst-case conditions where the high source inductance tends to prolong arcing. However, in real power systems, X/R tends to fall as the system voltage falls [6].

Tests carried out at 208V and 480V with the barrier in place allowed the effect of X/R to be studied.

For low X/R arcs were sustainable at 208V with a 12.7mm gap from 4.5kA upwards, but arcing could not be sustained with 32mm gap at any level of bolted-fault current. Therefore, it is more difficult to sustain arcing if X/R is reduced (see results in section IIIB). At 480V, arcing could be sustained for all gap lengths.

When arcs were sustained, the arcing current was about 20% lower and the incident energy was about 25% lower for low X/R, but these effects were most significant for bolted fault currents above 10kA.

More testing is needed with lower bolted-fault currents to determine the critical levels, below which sustained arcing is not possible.

VII. CONCLUSIONS

The test procedure used in the IEEE1584 standard for arc flash testing uses vertical 3-phase electrodes with open tips pointing downwards. Phase conductors that terminate in open air are rarely, if ever, found in real equipment.

Tests have been carried out using the IEEE1584 vertical test conductor arrangements, but with the tips terminating in an insulating barrier, and also in real components such as power distribution blocks and fuseholders.

When terminated in an insulating block, the downward movement of the arcs is arrested, and instead a plasma cloud is ejected at right angles to the plane of the conductors. This produces a pattern of plasma flow which is similar to that produced with horizontal electrodes.

With an insulating barrier, arc lengths and voltages are lower, the arcing currents are higher, and the maximum energy density, which is found on the middle calorimeter, is much higher than measured with the standard IEEE 1584 setup. Self-sustaining arcs can also be produced at 208V with relatively low levels of bolted-fault current. For systems with low X/R, the r.m.s. arcing current and incident energy are reduced, and sustained arcing is more difficult to obtain.

Erosion of the copper electrodes is also very much higher with the barrier in place, increasing the quantity of copper spray that is directed towards the outside of the box. The effects of large amounts of sprayed copper have important implications for PPE material testing. Different materials may have different propensities to absorb the molten copper and the associated latent heats of condensation and solidification.

All of these considerations lead to the conclusion that the current standard vertical test arrangement with electrode tips in open air should be replaced with one which is more representative of real equipment.

Addition of an insulating barrier to the standard test setup is one option, but a simpler one would be to use a horizontal arrangement with open electrode tips pointing at the calorimeters, as this is close to being a worst case. However sustained arcing can be obtained at 208V with the insulating barrier, and this is an important advantage of using the barrier arrangement.

VIII. ACKNOWLEDGEMENTS

Thanks are due to Craig McKenzie and John Rodrigues from the Frederick J Kozacka High-Power Test Laboratory and Gene O'Connell from Tech Imaging Services for their help in conducting the experiments.

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Simplified Arc Flash Hazard Analysis Using Energy Boundary Curves

By Antony C. Parsons, W. Blane Leuschner, and Kevin X. Jiang, members, IEEE Department of Energy

I. INTRODUCTION

Recent work in characterizing the potential arc flash hazards in electric power systems has led to an increased awareness of the hazards faced by those who work on or near exposed energized equipment. An arc flash hazard assessment must be performed in order to determine the level of personal protective equipment (PPE) that the one performing such work needs in order to be adequately protected. Performing an arc flash hazard analysis using the equations and procedures defined in IEEE 1584 satisfies this need. The arc flash study is often performed in conjunction with short-circuit and device coordination studies of the facility.

Short-circuit and coordination studies in the industrial facilities in the U.S. have typically extended from the service entrance equipment through the low-voltage (LV) switchgear or motor-control centers (MCCs) in the facility. If the scope of the arc flash study is the same as for the other studies, many locations where workers may be exposed to hazards will go "unanalyzed" equipment control panels, disconnect switches, junction boxes, etc. Since an arc flash analysis requires the determination of short-circuit levels and the evaluation of overcurrent protective device (OCPD) characteristics, the system studies may need to be extended to cover this equipment.

This can cause field data-collection requirements and analysis time required for the studies to grow tremendously and can ultimately require several times the effort needed to execute the more traditional study work scope. For this reason, the use of a simplified arc flash analysis method can be of great benefit when extending arc flash studies to include most or all distribution equipment in an industrial facility.

II. CONSTANT-ENERGY EQUATION

The "incident energy" is defined in IEEE 1584 as "the amount of energy impressed on a surface, a certain distance from the source, generated during an electrical arc event" [1].

The incident energy at any given point in a power system may be calculated as

$$E = 4.184 C_f E_n \left(\frac{t}{0.2}\right)\left(\frac{610^x}{D^x}\right) \left(\text{J/cm}^2\right) \qquad (1)$$

where C_F is a calculation factor based on system voltage (1.5 for voltages of 1 kV or less; 1.0 for voltages above 1 kV), En is the normalized incident energy (J/cm2), t is the arcing fault duration (in seconds), D is the working distance from the arc source (in millimeters), and x is the distance exponent from Table 4 of IEEE 1584.

For a given type of equipment (e.g., a 480-V MCC or a 208-V panelboard), C_F and x will be constant, as will be the default value for D. The values of E_N and t will vary, depending on the available fault current at the location under consideration and the characteristics of the upstream OCPD.
Equation (1) can be rewritten as

$$t = \frac{E}{A_1 E_n} \text{ (in seconds)} \qquad (2)$$

where A_1 is a constant defined as

$$A_1 = 4.184 \frac{C_f}{0.2}\left(\frac{610^x}{D^x}\right). \qquad (3)$$

IEEE 1584 defines the normalized incident energy as

$$\log E_n = K_1 + K_2 + 1.081 \log I_a + 0.0011G \qquad (4)$$

where K_1 is a constant related to equipment configuration (-|0.792 for "open-air" configurations; -|0.555 for enclosed equip-

ment), K_2 is a constant dependent on system grounding (-|0.113 for grounded systems; zero for ungrounded or impedance-grounded systems), 1_a is the arcing fault current (in kiloamperes), and G is the bus gap between conductors (in millimeters).

All the terms on the right-hand side of (4) other than 1_a are fixed for a given type of equipment. Simplifying (4) and combining with (2) yield

$$t = \frac{E}{A_1 A_2' I_a^{1.081}} \text{ (in seconds)} \quad (5)$$

where A_2 is a constant defined as

$$A_2 = K_1 + K_2 + 0.0011G \quad (6$$

$$A_2' = 10^{A_2}. \quad (7$$

Once the constants are defined based on the equipment and system configuration, an incident energy value E can be chosen, and (5) can be used to define a series of time-current points that correspond to the selected incident energy level.

As shown in [2], the curve connecting the time-current points corresponding to a given incident energy level appears linear on a log-log graph.

Equation (5) can be applied at locations within the IEEE 1584 range of applicability (208 V–15 kV, three phase, and with available bolted fault current levels of 700 A–106 kA).

For locations that fall outside of the range of the empirically derived IEEE 1584 equations, the IEEE 1584 equation based on the Lee method [3] can be used to define the constant-energy curves. Incident energy is defined as

$$E = 2.142 \times 10^6 V I_{bf} \left(\frac{t}{D^2} \right) \text{ (J/cm}^2\text{)} \quad (8)$$

where V is the system voltage (in kilovolts), I_{bf} is the bolted fault current value (in kiloamperes), t is the arc duration (in seconds), and D is the working distance (in millimeters). Equation (8) can be rearranged to solve for the arc duration and becomes

$$t = \frac{ED^2}{2.142 \times 10^6 V I_{bf}}. \quad (9)$$

Unlike (5), (9) is based on the bolted fault current, but the arcing fault current value is still required so that the arc duration can be determined. For voltages over 15 kV, IEEE 1584 recommends assuming that the arcing fault current is equal to the bolted fault current. For LV systems, the assumption from [3] that the arcing fault current equals half the available bolted fault current should be used instead.

Hazard/Risk Category	PPE Minimum Arc Rating (cal/cm^2)	PPE Minimum Arc Rating (J/cm^2)
0	N/A[B]	N/A[B]
1	4	16.74
2	8	33.47
3	25	104.6
4	40	167.36

A – From Table 130.7(C)(11) of NFPA 70E-2004 [4]
B – Category 0 clothing is allowed for incident-energy exposures of up to 8.36 J/cm^2 (2.0 cal/cm^2)

TABLE I
SUMMARY OF PROTECTIVE CLOTHING CATEGORIESA

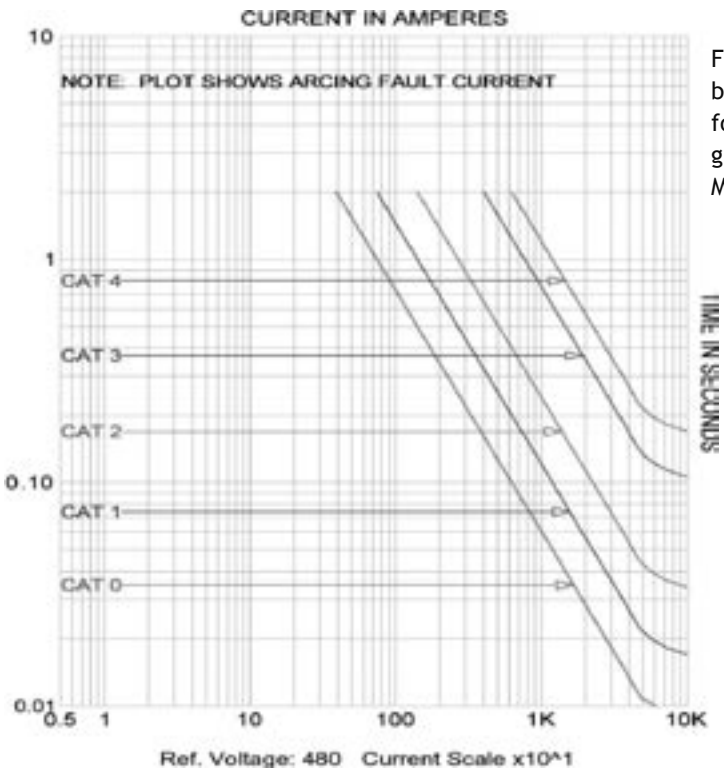

Fig. 1. Energy boundary curves for 480-V solidly grounded panel/MCC.

III. ENERGY BOUNDARY CURVES

National Fire Protection Association (NFPA) 70E-2004 [4] defines five arc flash PPE categories based on the available incident energy level at a given location. These are summarized in Table I.

By setting E in (5) or (9) equal to one of the minimum arc rating values shown in Table I, a constant-energy curve can be defined, which corresponds to the maximum incident energy level allowed for that PPE category.

For example, for PPE category 0 (E = 8.36 J/cm2) and analysis at an MCC on

a 480-V solidly grounded system, (5) becomes

$$t = 0.7254 I_a^{-1.081} \text{ (in seconds)}. \quad (10)$$

The time–current relationships can be calculated for each PPE category to define a set of constant-energy curves. The curves corresponding to each PPE category for this example are shown in Fig. 1. Note that these curves are cut off at a maximum time of 2 s. Clause B.1.2 of the IEEE 1584 states that, in many situations, 2 s is a "reasonable" maximum fault duration for use in calculations. The constant-energy curves can be extended beyond this point if necessary. The curves are also cut off at 100-kA arcing fault current. The IEEE 1584 empirical equations are applicable up to 106-kA bolted fault current. For a solidly grounded 480-V panel, this yields an arcing fault current of 49.3 kA. Above this level, (9) was used to extend the curves. In this case, the Lee method produces a less conservative result than the IEEE 1584 empirical equations; thus, the curves shown in Fig. 1 are interpolated between 49.3 kA and the time–current point calculated using (9) at 100-kA arcing fault current. A similar transition point between the IEEE 1584 empirical method and the Lee method may be calculated for each type and voltage class of equipment.

The leftmost curve in Fig. 1 ("CAT 0") corresponds to an incident energy level of 8.36 J/cm2. For time–current points that fall below or to the left of this curve, the available incident energy will be less than 8.36 J/cm2. For points above or to the right of this curve, the available incident energy will be greater than 8.36 J/cm2. Since this incident energy value marks the transition from Category 0 to Category 1 PPE, the "CAT 0" curve defines the boundary in Fig. 1 between time–current points, where Category 0 PPE is adequate and those where it is not. Since the other curves are calculated based on maximum incident energy levels for the other PPE categories, the "CAT 1"–"CAT 4" curves define the upper limits on the time–current plot for each of the other PPE regions. These particular constant-energy curves are denoted as the "energy boundary" curves. While Fig. 1 shows only the energy boundary curves for a solidly grounded 480-V MCC or panel, a set of energy boundary curves can be generated for any type or class of equipment — 480-V switchgear, medium-voltage equipment, etc.

IV. APPLICATION TO ARC FLASH ANALYSIS

The energy boundary curves may be used as the basis of a simplified arc flash analysis method that is particularly useful when applied in systems where many circuits are fed from a common bus. Examples of this include facilities where plug-in busway feeds many panels, control panels, or other equipment on a factory floor or in facilities where LV MCCs containing many branch devices

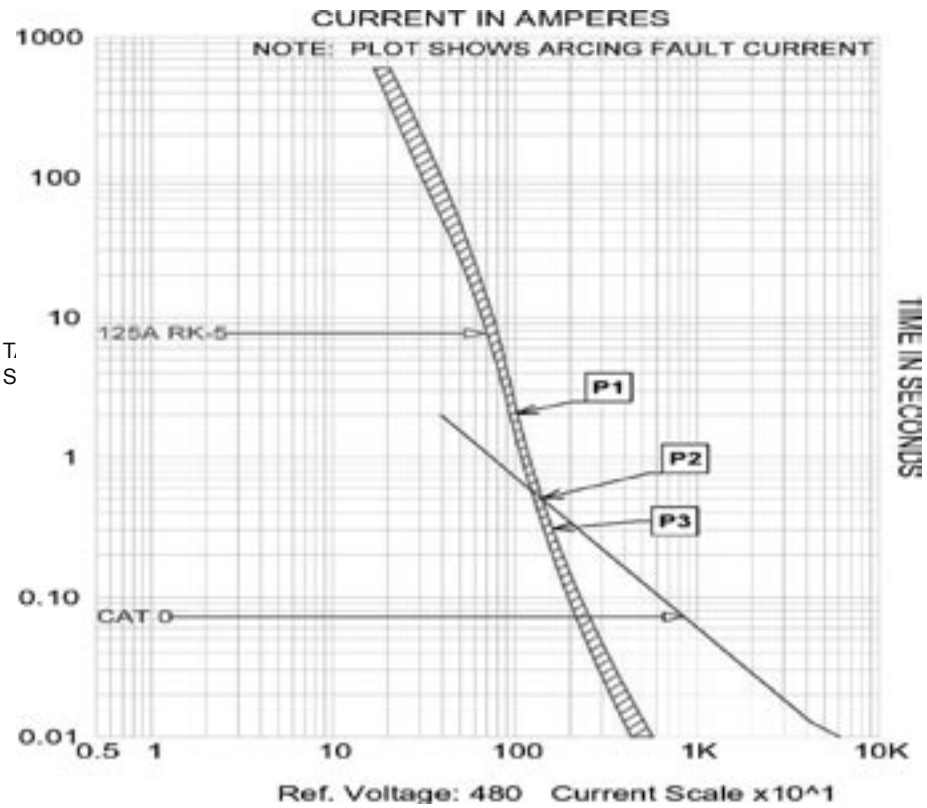

Fig. 2. Selected points on the 125-A RK-5 fuse curve.

Point	Arcing FC (kA)	Arc Duration (Sec.)	Incident Energy (J/cm^2)
P1	1.05	2.00	24.2
P2	1.42	0.50	8.36
P3	1.62	0.30	5.87

TABLE II
INCIDENT ENERGY VALUES AT SELECTED POINTS IN FIG. 2

feed similar load equipment. The energy boundary curves allow for a quick determination of the required PPE level — although not the exact incident energy level — at such locations. In this section, three examples will be given to illustrate the application of the energy boundary curves in arc flash analysis.

A. 125-A FUSED DISCONNECT

Consider Fig. 2, which shows the time-current characteristics of a 125-A class RK-5 LV fuse and the Category 0 PPE energy boundary curve for a 480-V solidly grounded MCC.

Three time-current points — P1, P2, and P3 — are shown on the plot. P1 is the point where the fuse total clearing curve intersects 2 s, at an arcing fault current of approximately 1046 A. P2 is where the Category 0 energy boundary and total clearing curves of the fuse intersect, at 1422 A and 0.5 s. P3 is the point where the total clearing curve of the fuse intersects 0.3 s on the time axis, corresponding to 1623-A arcing fault current.

The incident energy level at each point, calculated using the IEEE 1584 empirical equations, is shown in Table II.

As seen in Fig. 2, point P1 falls above the CAT 0 energy boundary curve. Table II shows that the calculated incident energy level at P1 is higher than the Category 0 limit. P3 falls below the energy boundary curve; thus, the incident energy level is less than the Category 0 limit, and Category 0 PPE is adequate for this location. At P2, which is a point on the energy boundary curve, the incident energy is exactly equal to the upper limit for Category 0 PPE.

P2 — the intersection of the selected energy boundary curve and OCPD characteristic curve—is the key to the simplified analysis method. Since the slope of the fuse curve is steeper than that of the energy boundary curve, the incident energy at the downstream bus drops as the available arcing fault current increases. For all arcing fault currents above this intersection value, which is the minimum arcing fault current (I_{am}) value, the PPE corresponding to the selected energy boundary curve will be adequate, while arcing fault currents falling below I_{am} will require a higher category of PPE.

To extend this example, suppose that several 125-A RK-5 fuses are applied in several busway plug-in disconnects that, in turn, each feed a 125-A panelboard. What PPE category is required at each panel?

The minimum arcing fault current corresponding to Category 0 PPE for this particular case is 1422 A; thus, as long as the arcing fault current level at the panels exceeds 1422 A, then Category 0 PPE will be adequate at each location.

The IEEE 1584 empirical model calls for the calculation of two incident energy values for each bus in LV systems — one using 100% of the calculated arcing fault current and a second using 85% of the calculated value. The higher of the incident energy values is then reported as the single incident energy level for that bus. Since the incident energy increases as the available fault current decreases at equipment protected by a fuse, the worst case incident energy value will be the one calculated using the 85% arcing fault current. In this case, the 1422 A is taken to be the "85% value" for the arcing fault current at the panels. The "100% value," which corresponds to the target arcing fault current (I_{at}; 1673 A in this example), is the level of arcing fault current that must be present at each panel (per the IEEE 1584 equation for arcing fault current) in order for Category 0 PPE to be adequate. For LV systems, this 85%/100% relationship between the minimum and target arcing fault current levels will often hold true.

The arcing fault current is calculated in the IEEE 1584 empirical model as

$$\log I_a = K + 0.662 \log I_{bf} + 0.0966 V + 0.000526 G + 0.5588 V (\log I_{bf}) - 0.00304 G (\log I_{bf}) \quad (11)$$

where I_a is the arcing fault current (in kiloamperes), K is a constant related to equipment configuration (-|0.153 for "open" configurations and -|0.097 for "box" configurations), Ibf is the three-phase symmetrical rms bolted fault current (in kiloamperes), V is the system voltage (in kilovolts), and G is the "bus gap" between conductors (in millimeters).

Collecting terms in (11) and solving for the arcing fault current I_a yield

$$I_a = A_4' I_{bf}^{A_3} \text{ (kA)} \quad (12)$$

where A_3 and A_4 are constants defined as

$$A_3 = 0.662 + 0.5588 V - 0.00304 G \quad (13)$$

$$A_4 = K + 0.0966 V + 0.000526 G \quad (14)$$

Solving (12) for the bolted fault current I_{bf} yields

$$I_{bf} = \left(\frac{I_a}{A_4'} \right)^{-A_3} \text{ (kA)}. \quad (16)$$

Equation (16) can be used to determine a target bolted fault current (I_{bf}) value, which is the minimum bolted fault current level at the local bus (the one being analyzed) required to produce an arcing fault current equal to I_{at}. The relationship between I_{at} and I_{bf} varies, depending on the type of equipment under consideration and the system grounding. Applying (16) to a 480-V panelboard with a standard bus gap (25 mm) in a solidly grounded system gives

$$I_{bf} = (1.0902 I_{at})^{1.1707} \text{ (kA)}. \quad (17)$$

An Iat of 1673 A gives a value of approximately 2.02 kA for I_{bf}. Therefore, as long as the available bolted fault current at the panelboards is greater than 2.02 kA, Category 0 PPE will be adequate. If detailed fault current information is available at each panel, then the analysis may be straightforward but not necessarily much more efficient than using a computer analysis package to calculate arc flash levels at each panel. However, if short-circuit calculations have not been performed to this level in the system,

the analysis using the energy boundary curves can reduce the required data collection and analysis times required to determine the appropriate PPE category at the downstream panels.

Assume that the feeder to each panelboard consists of one #1 American wire gauge (AWG) copper conductor per phase in steel conduit. The impedance of the conductor is 0.170 Ω per 1000 ft (305 m) at 75C [5]. The available three-phase bolted fault current at the busway feeding the panels is 10 kA.

As long as the length of the feeder conductor to any panel does not exceed approximately 790 ft (241 m), the three-phase bolted fault current level at the panels will be 2.02 kA or higher. For feeders shorter than this maximum distance, the three-phase bolted fault currents exceed I_{bf}, and the fuse will clear the arcing fault at a point below/left of the Category 0 energy boundary curve (e.g., P3 in Fig. 2). This demonstrates that the Category 0 PPE is adequate. Since such long feeder conductors are not common for small circuits in industrial facilities, it may now be possible to say that Category 0 PPE is appropriate for all 125-A panels fed from this busway even without knowing the exact length of each feeder or performing a detailed analysis at each panel.

This analysis is sensitive to the minimum arcing fault current I_{am}, the bolted fault current at the busway (the remote bus bolted fault current I_{rb}), and the impedance of the feeder conductor. When extending the analysis beyond a single remote bus (e.g., in a facility which has several feeder bus ducts serving 125-A panels), the worst case fault current and conductor impedance values may be used to further simplify the analysis.

Suppose that the facility under study also has a second bus duct with a minimum I_{rb} value of 5 kA and that some of the 125-A panels fed from this busway are fed by #2 AWG copper conductor, the smallest allowable for this feeder conductor per National Electrical Code Article 240 [6]. Based on the #2 AWG conductor and the 5-kA value for I_{rb}, the maximum feeder length drops from the previously reported 790 to 478 ft (146 m).

If no feeder is longer than this maximum length, then this shows that Category 0 PPE is adequate for all 125-A panels fed from busway in the facility. This type of analysis can also be extended to cover other size fuses or circuit breakers.

B. SMALL OCPDS

Fig. 3 shows the time–current curve for a 30-A 480-V circuit breaker and the Category 0 PPE energy boundary curve for a solidly grounded panel/MCC. Since the energy boundary curve is cut off at 2 s, the OCPD time–current and energy boundary curves never intersect. This indicates that a worker would have to be exposed to the arcing fault for longer than 2 s in order to be exposed to a total incident energy level of 8.36 J/cm2. If 2 s is an appropriate maximum arcing time, then Category 0 PPE is adequate at any equipment fed from this breaker, regardless of the available bolted fault current

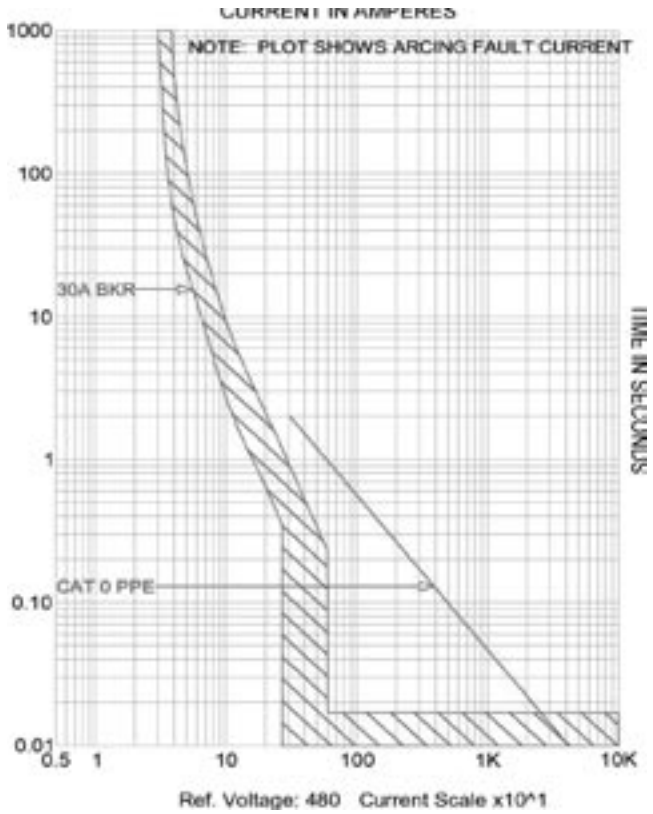

Fig. 3. 30-A breaker curve and CAT 0 PPE curve.

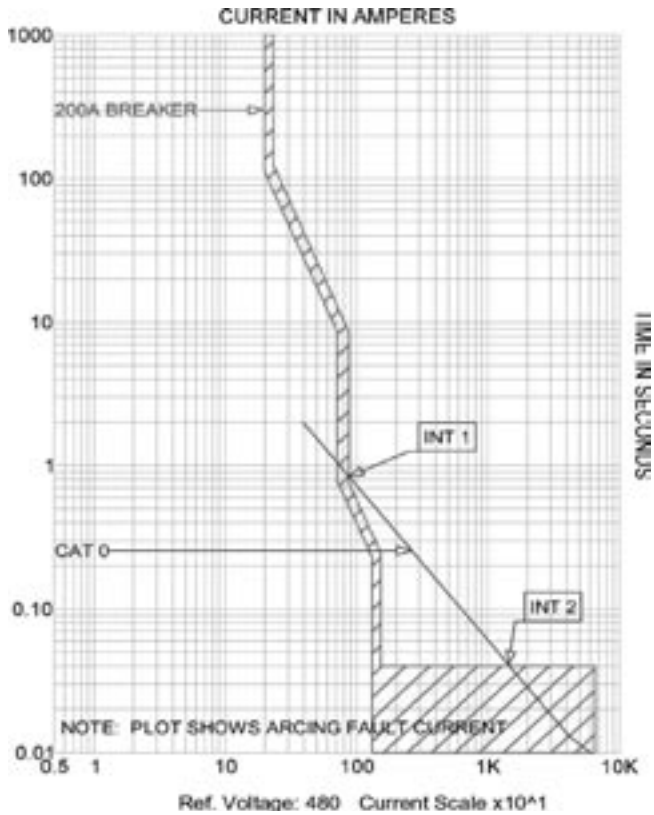

Fig. 4. 200-A breaker trip curve and CAT 0 PPE curve.

at the remote bus or the size and length of the associated feeder or branch circuit conductor.

Similarly, the energy boundary curves may not intersect fuse total clearing curves below a certain ampere rating.

C. LARGER CIRCUIT BREAKER

For larger circuit breakers, the energy boundary curves will intersect the breaker's time–current trip curve. If the available fault current is high enough, the energy boundary curves may intersect the breaker's time–current curve more than once, as shown in Fig. 4. The first intersection point, "INT1" in Fig. 4, corresponds to the minimum arcing fault current I_{am}, as discussed in Section IV-A. The second intersection point "INT2" indicates that, for very high arcing fault current levels, the instantaneous tripping of the breaker is not sufficient to limit the downstream arc flash incident energy below the Category 0 PPE maximum of 8.36 J/cm2. For an adjustable-trip breaker, the lower intersecting value (INT1) varies, depending on the trip settings of the breaker; thus, these must be considered when employing the energy boundary method with such a device.

Otherwise, the analysis procedure is the same once the minimum arcing fault current value has been established. For the upper intersecting value (INT2), the intersection represents a maximum arcing fault current value $I_{a.max}$. This value, along with the available bolted fault current at the remote bus and the conductor impedance per unit length, can be used to determine a minimum allowable circuit length that will allow for a given PPE class at downstream equipment.

Since the circuit breaker has a definite-time characteristic above its instantaneous pickup level, the incident energy value calculated for high-level faults based on the 85% arcing fault current will be less than that calculated based on 100% arcing fault current. Therefore, for the upper intersection point, the maximum arcing fault current $I_{a.max}$ is equal to the maximum target arcing fault current $I_{at.max}$.

If the energy boundary and circuit breaker trip curves do intersect twice, the circuit under consideration will have both minimum and maximum distances that are allowable for the given PPE category.

For some devices — such as breakers that will trip within one 60-Hz cycle — the fault current levels required to reach the upper intersection point are very high (e.g., ≥ 80-kA bolted fault current at the remote bus); thus, the minimum circuit length may only need to be considered in special circumstances. For current-limiting molded-case breakers, where the trip time drops to 0.01 s or less relatively quickly, the minimum length may not need to be considered at all.

D. CALCULATING THE FLASH-PROTECTION BOUNDARY

The flash-protection boundary is defined in NFPA 70E-2004 as "an approach limit... within which a person could receive a second degree burn if an electrical arc flash was to occur" [4].

The IEEE 1584 provides an equation for the calculation of the flash-protection boundary distance for the empirically derived model that is based primarily on the normalized incident energy level and the duration of the arcing fault. When an energy boundary analysis is performed, the maximum incident energy level at each bus is established, but exact values for the normalized incident energy and fault clearing time are not determined.

However, the IEEE model can still be used to calculate a maximum flash-protection boundary distance corresponding to each PPE class. Since the exact arc flash levels are not calculated with this procedure, choosing the flash-protection boundary distance based on the maximum incident energy level for each PPE category ensures a conservative result.

From (1), the incident energy level (E_{WD}) at the working distance (D_{WD}) is calculated as

$$E_{WD} = 4.184 C_f E_n \left(\frac{t}{0.2}\right)\left(\frac{610^x}{D_{WD}^x}\right) \qquad (18)$$

while the incident energy level (E_B) at the flash-protection boundary distance (D_B) is equal to

$$E_B = 4.184 C_f E_n \left(\frac{t}{0.2}\right)\left(\frac{610^x}{D_B^x}\right). \qquad (19)$$

For a given arcing fault event, all quantities in (18) and (19) are equal except for those that vary with distance — E_B, E_{WD}, D_B, and D_{WD}. Dividing (19) by (18) and simplifying yield

$$\frac{E_B}{E_{WD}} = \left(\frac{D_B}{D_{WD}}\right)^{-x} \qquad (20)$$

where x is the distance exponent from IEEE 1584. Equation (20) gives a maximum flash-protection boundary distance of 624 mm (25 in) for Category 0 PPE (maximum of 8.36 J/cm2) and a 480-V panel/MCC.

V. CASE STUDY—APPLYING THE ENERGY BOUNDARY METHOD

As part of a short-circuit, coordination, and arc flash study conducted at an industrial facility, PPE requirements were to be determined downstream of all 480-V MCCs in the facility. Fifty MCCs, each containing an average of 20 fused branch circuits, were present. The MCCs feed numerous equipment and process control panels, disconnect switches, etc., where workers are sometimes exposed to energized equipment. To perform exact calculations at each piece of downstream equipment, the data on protective device types and sizes in each MCC bucket, as well as on conductor size and length for each circuit, would need to be collected. In addition, the extra 1000 buses would need to be modeled and evaluated with the analysis software program. Initial estimates on the data-collection effort alone were in the 250 man-hour range.

Instead, the energy boundary method was applied for the evaluation of PPE requirements downstream of the MCCs. The study was performed in two stages—first, data were collected down to the MCC level, and short-circuit levels were calculated to that point. In addition, full data on MCC branch OCPDs and conduc-

tor sizes were collected from a few representative MCCs in the facility. Based on the calculated short-circuit results and preliminary MCC data, the energy boundary method was used to determine that Category 0 PPE was adequate for all equipment directly fed from the MCCs as long as circuit lengths were less than approximately 400 ft (122 m) and OCPD sizes were less than 150–175 A. (The required PPE at the MCCs themselves was most often higher than Category 0).

During the second on-site visit, data-collection efforts focused on equipment fed from the MCCs via long circuits and/or large OCPDs, as the preliminary analysis identified these locations as the potential "trouble spots". The total data-collection time at or beyond the MCCs was reduced from an estimated 250 to 12 h, which is a reduction of approximately 95%.

In this case, the simplified analysis technique allowed for the extension of the arc flash analysis to include virtually every piece of equipment in the facility with minimal added cost and effort. The energy boundary method has also been applied at other sites, including light industrial facilities, automotive plants, and hospitals, with similar results.

VI. CONCLUSION

In Section II, equations based on the IEEE 1584-2002 empirical model were derived to define constant arc flash incident energy lines that appear linear on a log–log plot. When these constant-energy lines are selected to correspond to maximum arc flash levels for various categories of PPE, then the lines define boundaries between regions on a time–current plot, which correspond to the PPE categories. These energy boundary curves can be used as a basis for a systematic simplified method for arc flash hazard analysis.

The energy boundary method applies these boundary curves and allows for efficient determination of required PPE levels and flash-protection boundary distances, particularly when analyzing numerous buses fed from a common point, such as an MCC or plug-in busway. The energy boundary curves and the associated analysis method are based on the equations presented in the IEEE 1584-2002, not on "rules-of-thumb" or "trial and error" analysis. While the examples presented deal with the application of the energy boundary method to 480-V fuses and circuit breakers, the equations can be applied to any type of OCPD on any power system that falls within the range of applicability of the IEEE 1584-2002.

Energy boundary analysis has proven to be a useful tool for efficiently extending the scope of arc flash studies. Other potential applications for the energy boundary method include the following.

1) As an aid in device coordination, similar to that shown in [2]. The energy boundary curves can be used to help determine breaker or relay settings that will help to minimize arc flash levels downstream.

2) As a guide for field data-collection efforts for an arc flash analysis. A preliminary energy boundary analysis can identify buses where the required PPE levels will be low, thereby allowing the data-collection efforts to focus in on areas which have potentially higher energy levels.

3) As a means to perform a quick PPE assessment for field work in an unknown facility. Using the energy boundary method, it may be possible to determine the required PPE levels based upon minimal information, which can be useful when performing a hazard/risk assessment in a facility where a full arc flash analysis has not yet been performed.

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Low-voltage Current-limiting Fuses Can Reduce Arc Flash Energy

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Current-limiting fuses, in their current-limiting range, reduce the available short-circuit current and clear faults in one-half cycle or less. Available fuse test data, such as let-through I2t and peak let-through current, is based upon single-phase bolted-fault tests at full voltage.

Currently, there is no data available that relates single-phase current-limiting fuse test data with energy released by downstream three-phase arcs. A three-phase 600-V test program was conducted using Class L and RK1 fuses to determine the let-through arc energy and the incident energy produced 18 in away from a three-phase arc in a 20-in cubic box. Incident energy produced by the downstream arc is correlated with the degree of current limitation and fuse bolted-fault test data. The benefit provided by current-limiting fuses in reducing arc flash energy is quantified.

I. INTRODUCTION

Since energy is the integral of power with respect to time, one would expect, and tests have confirmed, that the thermal incident energy from an electric arc exposure is directly proportional to the time duration of the arc [1], [2]. Any mechanism which detects the presence of the arc and opens the circuit in a relatively short time is effective in limiting the amount of incident energy exposure created by the arc. One common class of protective equipment that provides quick circuit opening in the event of an arc with high currents is the current-limiting fuse. When operating in the current-limiting range, the fuse typically opens the circuit in less than 1/2 cycle or 8.3 ms.

Results of recent tests provide a method of estimating the thermal incident energy produced by three-phase arcs on 600-V electric power distribution systems [3]. The incident energy prediction algorithms in [3], however, cannot be used to determine incident energy from arcs produced by three-phase 600-V circuits with fuses in them. Within their current-limiting range, the fuses introduce additional impedance into the circuit and reduce the amount of energy that is produced by a three-phase arc.

Persons who design, operate, and maintain electrical power distribution systems have a need to know how much arc flash protection is provided for personnel by installing current-limiting fuses into electrical power distribution circuits. The authors decided to conduct three-phase arc tests on 600-V circuits with current-limiting fuses inserted in the circuit just ahead of the arc. Since a majority of electric arcs occur in electric equipment enclosures, the decision was made to enclose the three-phase arc in a 20-in cubic metal box, similar to the test setup used in [2] and [3].

The current-limiting fuses selected for testing included 400- and 600-A Class RK1 fuses and 800-, 1200-, 1600-, and 2000-A Class L fuses. The Class L fuses chosen are typically used in fused low-voltage power circuit breakers or bolted pressure switches.

The 400- and 600-A Class RK1 fuses are typically used in feeders, motor control center mains, bus duct plugs, or large motor starters.

II. CURRENT-LIMITING FUSE DATA

In order to determine the performance of current-limiting fuses, fuse manufacturers typically perform single-phase bolted-fault fuse tests based on the UL (U.S.)/ CSA (Canada)/ANCE (Mexico) tri-

national 248 series of standards. Table I shows average results of actual fuse tests performed on the fuse types selected for use in the three-phase arc tests. Note that the 248 series of standards calls out the maximum let-through values so that all fuses listed to the standard will have a uniform maximum let-through which can be utilized by equipment manufacturers and designers.

Manufacturers determine the fuse current-limiting and let-through characteristics from the fuse test data. Fuse let-through charts for Class RK1 and Class L fuses used in the three-phase arc tests are shown in Fig. 1. In order to read a fuse let-through chart, enter the axis at the available rms symmetrical short-circuit current. Move up until the appropriate fuse curve is intersected. Then, make a left turn, proceed horizontally until reaching the axis, and read the peak let-through current. To read the equivalent rms let-through current, start with the available rms short-circuit current on the axis. Move up until the fuse curve is intersected, turn to the left and proceed horizontally to the "A-B" line. Then, move down to the axis and read the equivalent rms let-through current. For example, in Fig. 1, assume an available short-circuit current of 100 000-A rms, and an 800-A Class L fuse. Beginning at 100 000 A on the axis, move up to the 800-A fuse line. Turn to the left and read the peak let-through current as 50 000-A peak. To read the equivalent rms let-through current, start out as above, but at the "A-B" line intersection, move down to read 22 000 equivalent rms amperes on the axis.

III. THREE-PHASE FUSE ARC TEST PROGRAM

A. TEST SETUP

All tests described herein were performed in the medium-current cell of a high-power test laboratory. In this test cell, the test board is connected by 1/2-in 8-in copper bus to the low-voltage side of a 300-MVA short-circuit delta-connected transformer bank. Primary transformer power was supplied from a 640-MVA (short circuit) synchronous alternator through a reactive load bank. The load

TABLE I
Average UL Fuse Bolted Fault Test Data

Fuse Description		Avail.	Test	Circuit	Meas.	Let-Through
Fuse Class	Rated Current	Sym. I kA	Voltage V	Power Factor	Peak I kA	Pt x 10^3 amp^2-sec.
RK1	400 A	16.8	612	6.0%	17.7	815.5
RK1	400 A	102.9	612	14.0%	32.5	778.7
RK1	400 A	208.0	604	16.0%	40.1	730
RK1	600 A	103.0	611	14.0%	44.6	2427
RK1	600 A	203.0	606	17.0%	55.9	2225
L	800 A	26.2	603	5.5%	35.4	3311
L	800 A	103.9	610	14.6%	50.1	3183
L	800 A	213.3	606	19.0%	67.6	3513
L	800 A	306.0	602	18.0%	73.2	3460
L	1200 A	26.2	603	5.5%	50.9	8704
L	1200 A	102.0	605	11.5%	69.1	9573
L	1200 A	213.2	613	19.0%	86.9	10344
L	1200 A	306	602	18.0%	126	17500
L	1600 A	25.8	606	6.0%	58.6	12789
L	1600 A	50.6	604	11.0%	66.0	12320
L	1600 A	103.4	607	16.0%	83.2	15783
L	1600 A	213.5	600	No Data	104	18050
L	2000 A	25.0	600	No Data	55.8	12500
L	2000 A	51.0	603	18.0%	78.9	18503
L	2000 A	102.6	519	18.0%	85.2	17856
L	2000 A	213.5	600	No Data	119	26250
L	2000 A	306.0	602	18%	129	17700

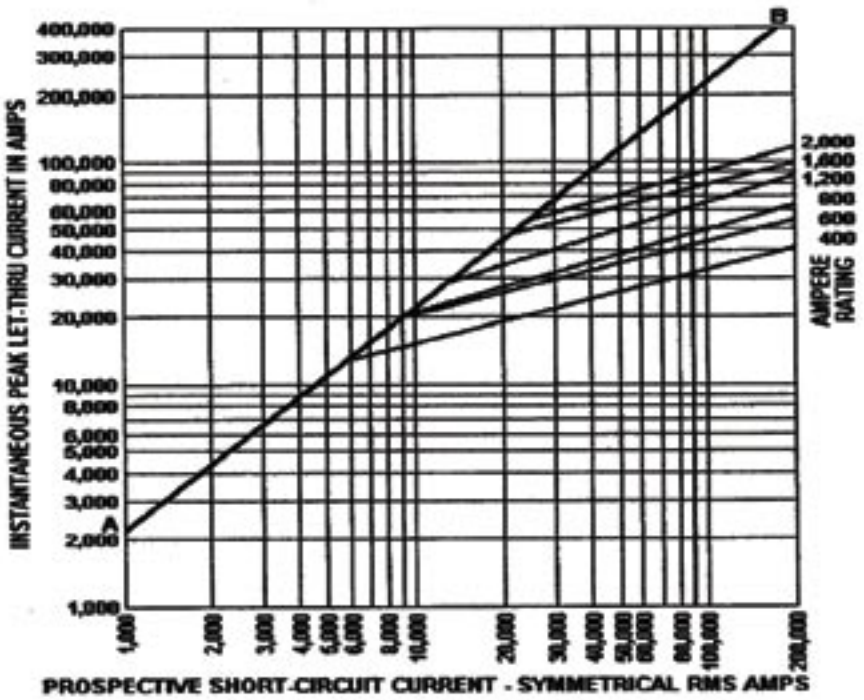

Fig. 1. Peak let-through chart - test fuses.

Fig. 2. Test setup.

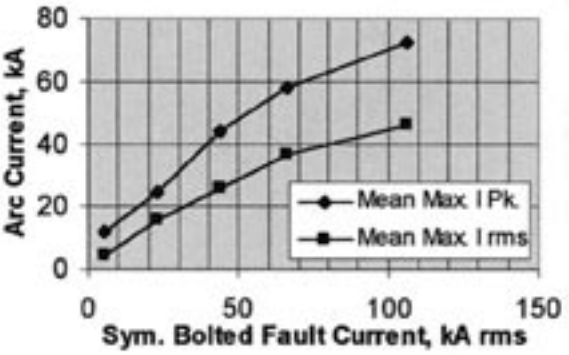

Fig. 3. Three-phase arc current as a function of bolted-fault current. Effect of arc impedance on current.

bank consisted of air-core inductors selected to yield the desired current/voltage combinations in the test cell. Rotation for the alternator was provided by a relatively small DC motor that, in turn,was powered from the electric utility through a solid-state DC drive. The 64,000-lb alternator rotor acts as a flywheel and at rated speed has 650 kJ of stored kinetic energy. Thus, the power delivered to the test cell for a short period of time may exceed the motor drive capability by several orders of magnitude. Power was delivered to the test cell through a 4-ft length of 1/2-in 6-in copper bus which was braced to withstand the 6-cycle bolted-fault shots.

One test setup was used for all three-phase arc testing. The test setup utilized electrodes mounted inside and 4 in from the back of an unpainted, carbon steel cubic box (20 in wide 20 in high 20 in deep) as shown in Fig. 2. The 4-in distance was selected to minimize damage to the rear wall of the box as well as to facilitate electrode maintenance during testing. Fuses were inserted into the test circuit electrically ahead of where the conductors entered the cubic metal box. Tests were conducted with the box ungrounded, since earlier testing [2] indicated that the ungrounded box produced the maximum incident energy.

TABLE II THREE-PHASE FUSE ARC TEST RESULTS: 600-V SYSTEM—1.25-IN ARC GAP

Arcing Bolted Fault Current kA	X/R Ratio	Current Limiting Fuse Type	Mean Max. Current kA rms	Mean Max. Peak Current kA Peak	Average Arc Energy kW-Sec	Average Let-through I²t Amp²-Sec X 10⁶	Arcing Cbl. Input Arc Energy/I²t kWA/cm²	Average Incident Energy cal/cm²	Mean Max. Incident Energy cal/cm²
106	7.9	None	46.86	72.3	4205	567777	0.0072	22.42	35.71
106	7.9	CL L-2000A	28.80	48.3	524	40574	0.0130	1.94	2.39
106	7.9	CL L-1600A	28.00	41.4	70	7444	0.0094	0.29	0.36
106	7.9	CL L-1200A	24.05	37.9	33	3490	0.0095	0.14	0.20
106	7.9	CL L-800A	19.35	34.8	45	3867	0.0115	0.18	0.22
106	7.9	CL RK1-600A	17.00	30.0	6	1170	0.0064	0.03	0.04
65.9	9.95	None	36.77	58.1	2918	360565	0.0081	16.21	21.29
65.9	9.95	CL L-2000A	25.50	36.7	915	71154	0.0107	6.48	8.24
65.9	9.95	CL L-1600A	22.97	35.3	179	14893	0.0113	0.86	1.24
65.9	9.95	CL L-1200A	20.15	33.9	39	3843	0.0098	0.18	0.24
65.9	9.95	CL L-800A	16.90	31.2	33	3040	0.0109	0.14	0.17
65.9	9.95	CL RK1-600A	16.95	27.0	12	1416	0.0095	0.05	0.09
44.1	11	None	25.67	44.4	1433	209772	0.0070	12.23	15.68
44.1	11	CL L-2000A	21.78	37.0	1440	111286	0.0132	9.90	13.00
44.1	11	CL L-1600A	22.80	33.9	141	13602	0.0103	0.73	0.92
44.1	11	CL L-1200A	18.60	28.2	50	4719	0.0107	0.24	0.30
44.1	11	CL L-800A	14.18	24.7	21	2086	0.0102	0.09	0.15
44.1	11	CL RK1-600A	12.33	21.2	11	1310	0.0087	0.05	0.07
22.6	4.9	None	15.80	24.3	875	73274	0.0120	5.93	7.79
22.6	4.9	CL L-2000A	15.95	25.2	2837	223106	0.0118	23.12	28.89
22.6	4.9	CL L-1600A	15.53	23.8	2837	223106	0.0116	7.01	8.47
22.6	4.9	CL L-1200A	12.33	22.2	527	28649	0.0213	4.65	6.33
22.6	4.9	CL L-800A	14.63	22.3	139	8431	0.0153	0.63	0.84
22.6	4.9	CL RK1-600A	12.25	20.2	23	2057	0.0091	0.10	0.15
22.6	4.9	CL RK1-400A	9.43	15.7	3	770	0.0048	0.02	0.03
5.04	15	CL RK1-600A	4.69	11.7	2760	61382	0.0536	21.06	26.39
5.04	15	CL RK1-400A	5.89	10.8	96	2126	0.0397	0.29	0.35

For each test, an array of seven copper calorimeters was located in front of the box, 18 in from the centerline of the electrodes. A set of three calorimeters was located in a horizontal row at the same height as the tip of the electrodes. A second set of three calorimeters was located in a horizontal row 6 in below the elevation of the electrode tips. The middle calorimeters in each set were aligned with the center electrode. A single calorimeter was located 6 in above the center electrode tip.

Hard-drawn copper conductors, diameter of 3/4 in, were used for the arc electrodes. Electrodes were vertically oriented in a flat configuration with a side–side spacing of 1.25 in, the spacing that was determined to produce maximum incident energy in previous tests [2]. Arcs were initiated by a #10 gauge wire connected between the ends of the electrodes. For all tests, it was necessary to install insulating support blocks between adjacent electrodes to prevent the electrodes from bending outward due to the extremely high magnetic forces created by the arc currents.

Open-circuit test voltages were selected at or above the nominal system voltage of 600 V. The bolted-fault current available at the test terminals was measured by shorting the electrodes together. The current-to-voltage transducers employed in the bolted-fault calibration shots were 30-m low-inductance current-viewing resistors. The voltage signals from these transducers were coupled to an eight-channel digital oscilloscope through analog fiber-optic links. The duration of all arc tests was selected to be 6 cycles (100 ms).

In order to quantify arc energy, phase currents and voltages were measured. Current transformers (CTs), 20 000/5 A, were employed for current measurement. Voltage signals from the CT burden were coupled through a 3-kHz low-pass RC filter to the digital oscilloscope. Phase voltages were measured with three resistive attenuators connected between the electrodes and the derived neutral configuration. The attenuator signals

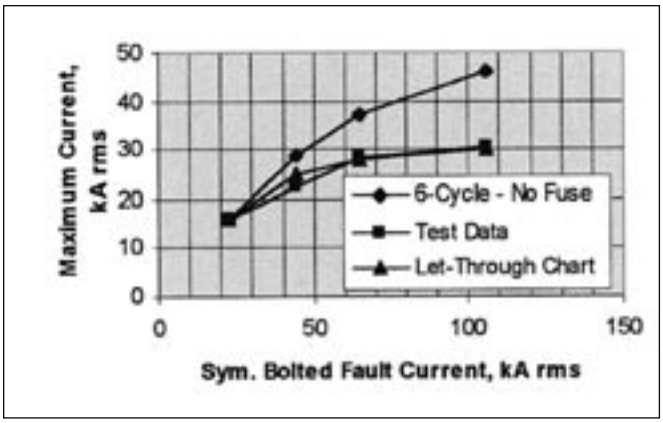

Fig. 4. Maximum current as a function of bolted-fault current - 2000-A Class L fuse.

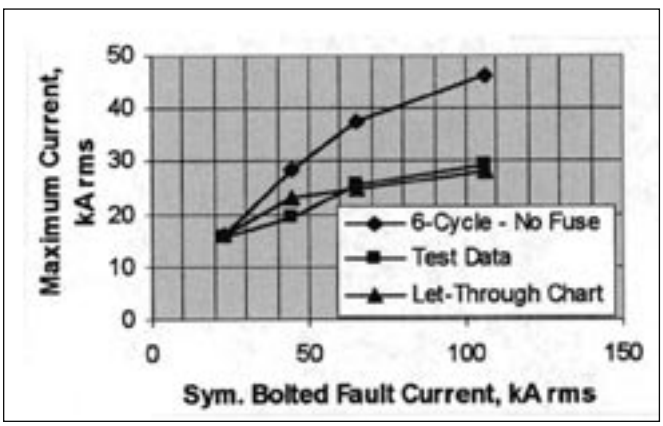

Fig. 5. Maximum current as a function of bolted-fault current - 1600-A Class L fuse.

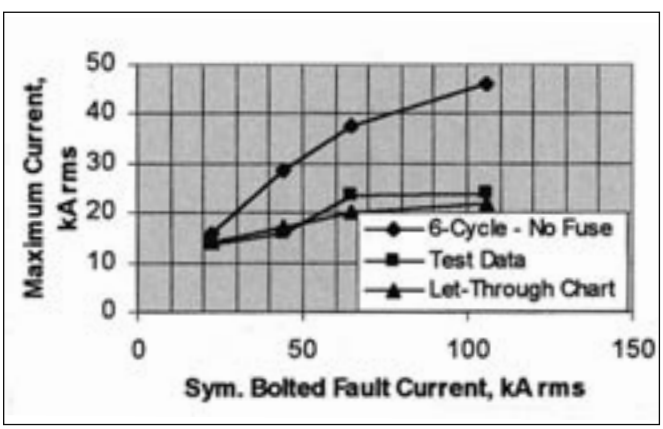

Fig. 6. Maximum current as a function of bolted-fault current - 1200-A Class Lfuse.

were coupled to the digital oscilloscope through the analog fiber-optic links and the 3-kHz filters.

The current and voltage waveforms were captured on the oscilloscope at a 20-kHz sampling rate. Upon capture of the voltage and current traces, the phase power curves versus time were obtained by multiplication of the phase current/voltage pairs. The phase energies were then obtained by integration

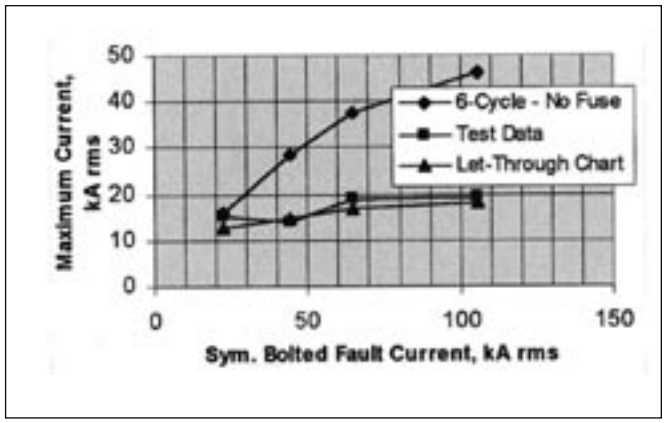

Fig. 7. Maximum current as a function of bolted-fault current - 800-A Class L fuse.

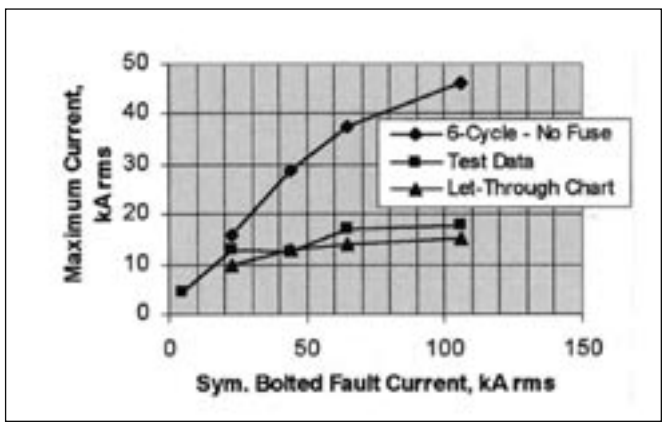

Fig. 8. Maximum current as a function of bolted-fault current - 600-A Class RK1 fuse.

of the phase power curves over the arcing interval. All of the described curve manipulation was performed using the menu/computation functions resident on the digital oscilloscope.

Incident energy was measured by the copper calorimeters mounted on stands. Copper calorimeter temperature rise data in degrees Celsius was converted into incident energy in cal/cm (conversion factor 0.135 cal/cm C). Sensor absorption measurements have determined that absorbed energy is equal to or greater than 90% of incident energy for copper calorimeters. Henceforth, incident and absorbed energy will be considered as equivalent, and the term incident energy will be used.

B. TEST SEQUENCE AND RESULTS

A series of three-phase arc tests was conducted during two one-week periods. The tests measured the incident energy 18 in from the arc electrodes for different available symmetrical bolted-fault currents. In order to reduce the impact of arc variability, multiple tests were run for each setup and the results averaged. Since arc duration varies slightly from test to test, a time-duration correction factor was applied to the temperature rise data from the seven copper calorimeter sensors to insure that each reported incident energy was based on an arc duration of 6 cycles. The mean incident energy for the seven sensors

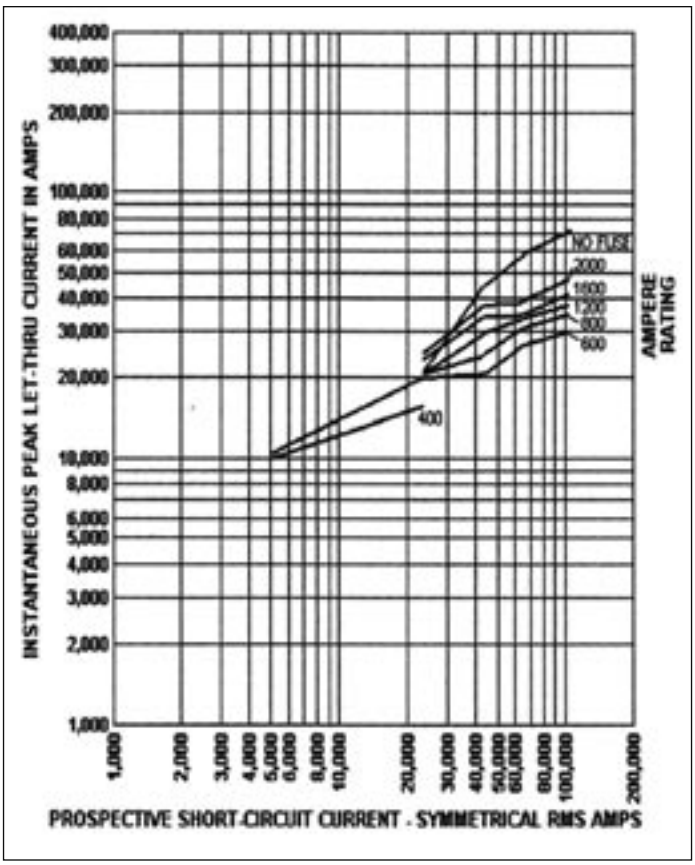

Fig. 9. Fuse performance chart for three-phase arcs.

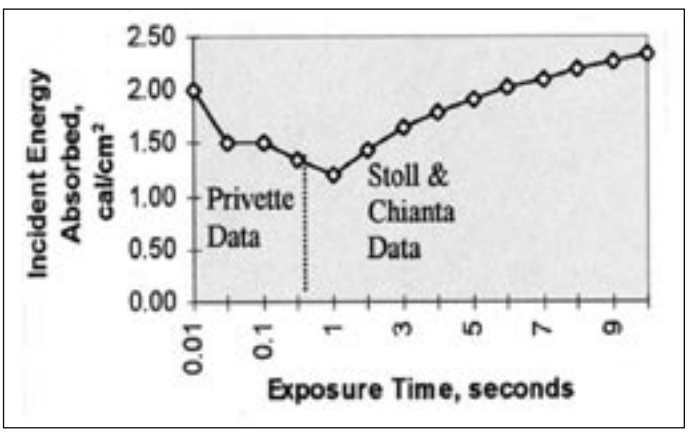

Fig. 10. Human tissue tolerance to second-degree burn. Second-degree burn energy limits.

and the mean maximum incident energy recorded by a single sensor were calculated for each test.

At each level of available bolted-fault current, tests were first conducted without any fuses in the test circuit. Then, fuses were inserted into the test circuit and tests repeated for each different size of current-limiting fuse. Test results are shown in Table II.

IV. ANALYSIS OF TEST DATA

Readers should be aware that data provided in this technical paper is based only upon measured incident energy under specified test conditions. Real arc exposures may be more or less severe than these laboratory-simulated arc exposures. The potentially hazardous effects of molten copper splatter, projectiles, pressure impulses, and toxic arc byproducts have not been considered in the test results or the analysis.

A. IMPACT OF ARC IMPEDANCE ON FAULT CURRENT

The fault current for a three-phase arcing fault is reduced below the available bolted-fault value due to the addition of the resistive arc impedance into the circuit. Fig. 3 shows the arc current as a function of available symmetrical rms bolted-fault current on the supply side of the arc. Note the significant reduction in current flowing through the circuit due to the arc impedance. For example, with an available symmetrical bolted-fault current of 66-kA rms, the three-phase symmetrical arc current is reduced to 36.8-kA rms, a current reduction of 44%. The introduction of the arc resistance into the circuit also lowers the effective X/R ratio of the circuit.

Given the available bolted-fault current on the supply side of a current-limiting fuse, using Fig. 3 one can estimate the amount of current that will be available to flow through the fuse in the event of a three-phase arcing fault downstream of the fuse. This reduced current value can then be applied to the let-through chart in Fig. 1 to determine the degree of current limitation that is provided by the fuse. For example, if the available bolted-fault current on the supply side of the fuse is 66 kA, then Fig. 3 indicates that the actual current that would flow in the event of a three-phase arc downstream of the fuse is 36.8 kA. Consider the effect of inserting a 1200-A Class L fuse into the circuit ahead of the arc location. Using the let-through chart in Fig. 1, enter the bottom of the chart at the available fault current of 36.8 kA, move up until the 1200-A fuse line is intersected, move left until the A–B line is intersected, and then move down and read the equivalent let-through current value of 20 kA. Thus, the insertion of the 1200-A Class L fuse into the circuit further reduced the arcing fault current from 36.8 to 20 kA, significantly reducing the incident energy available from the three-phase arc.

Figs. 4–8 show maximum rms current as a function of available symmetrical rms bolted-fault current for each test fuse except the 400-A Class Rk1 fuse (due to insufficient test data). The top line shows the maximum measured "no fuse" data, or the rms current that was measured without a fuse in the circuit. The other two plots show the maximum measured let-through rms current and the expected equivalent rms let-through current read from the let-through chart in Fig. 1 using the procedure described in the paragraph above. There is a very good correlation between the measured and expected let-through values.

A fuse performance chart can be constructed using the test data for performance of current limiting fuses when upstream of a three-phase arcing fault. Fig. 9 shows the locus line for

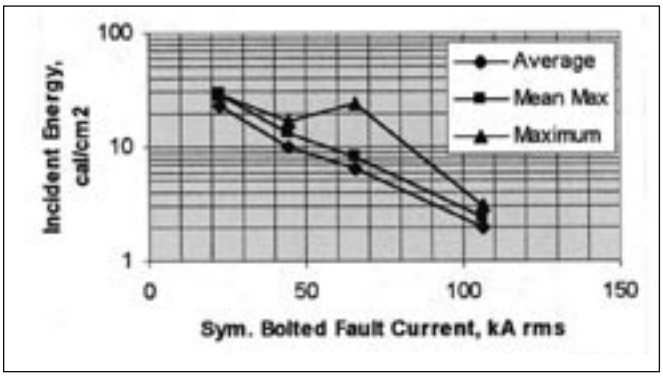

Fig. 11. Incident energy 18 in from three-phase arc downstream of 2000-A Class L fuse.

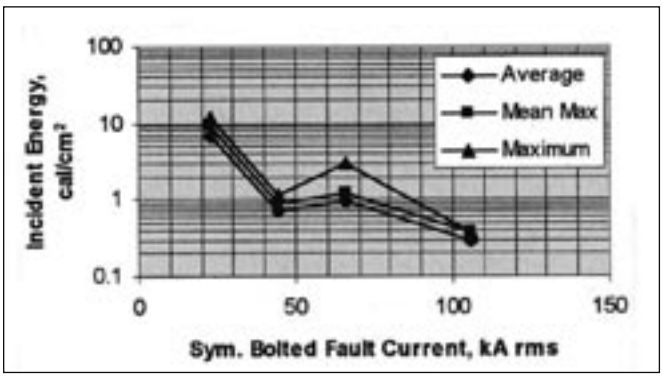

Fig. 12. Incident energy 18 in from three-phase arc downstream of 1600-A Class L fuse.

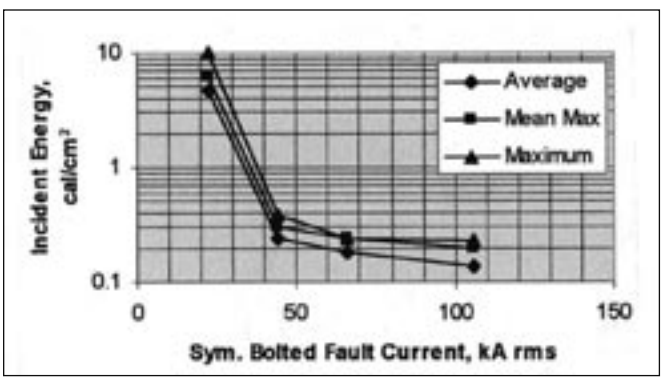

Fig. 13. Incident energy 18 in from three-phase arc downstream of 1200-A Class L fuse.

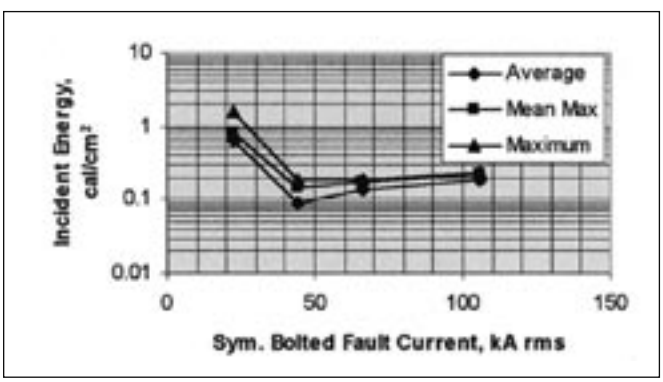

Fig. 14. Incident energy 18 in from three-phase arc downstream of 800-A Class L fuse.

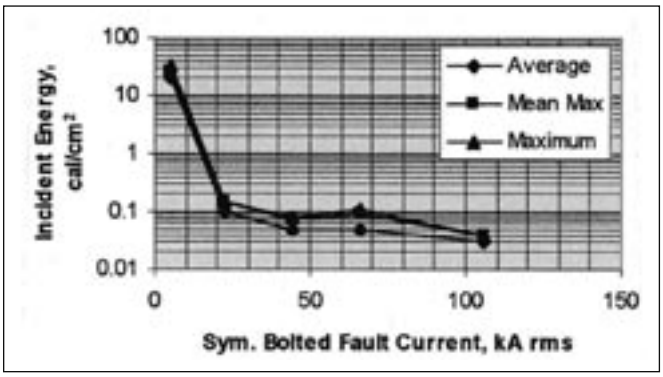

Fig. 15. Incident energy 18 in from three-phase arc downstream of 600-A Class RK1 fuse.

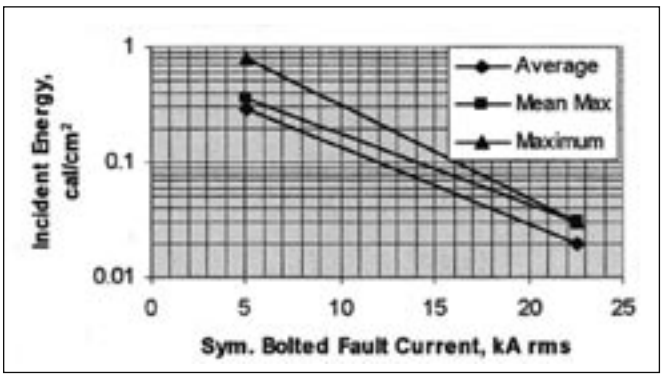

Fig. 16. Incident energy 18 in from three-phase arc downstream of 400-A Class RK1 fuse.

each fuse type determined by plotting peak let-through current against available bolted-fault current for each arc test. Fig. 9 can be used to determine the peak let-through current of a fuse when upstream of a three-phase arcing fault. Enter the bottom of the chart at the available symmetrical rms bolted-fault current level and move up until the fuse line is intersected. Then, move left to read the peak let-through current.

B. MEASURED INCIDENT ENERGY LEVELS

An incident energy level of 1.2 cal/cm was chosen as the minimum energy threshold for a second-degree burn of human skin based upon data shown in Fig. 10 [1]. If the measured incident energy in Table II exceeds 1.2 cal/cm , then the possibility exists for a second-degree burn of human skin.

Figs. 11–16 depict measured incident energy 18 in from the three-phase arc as a function of available bolted-fault current for each tested current-limiting fuse. Beginning with a 2000-A Class L fuse and working down to a 400-A Class RK1 fuse, these graphs show that once the current-limiting threshold is reached, the incident energy is dramatically reduced. For example, for 800-A Class L fuses (Fig. 14), the incident energy dropped below 0.5 cal/cm when the available bolted-fault current reached 44 100 A, and continued below that level at 69 500 and 106 000 A available. At 22 600-A bolted-fault current, the 800-A fuses were not as current limiting, showing a worse case incident energy of 1.54 cal/cm . Further testing could

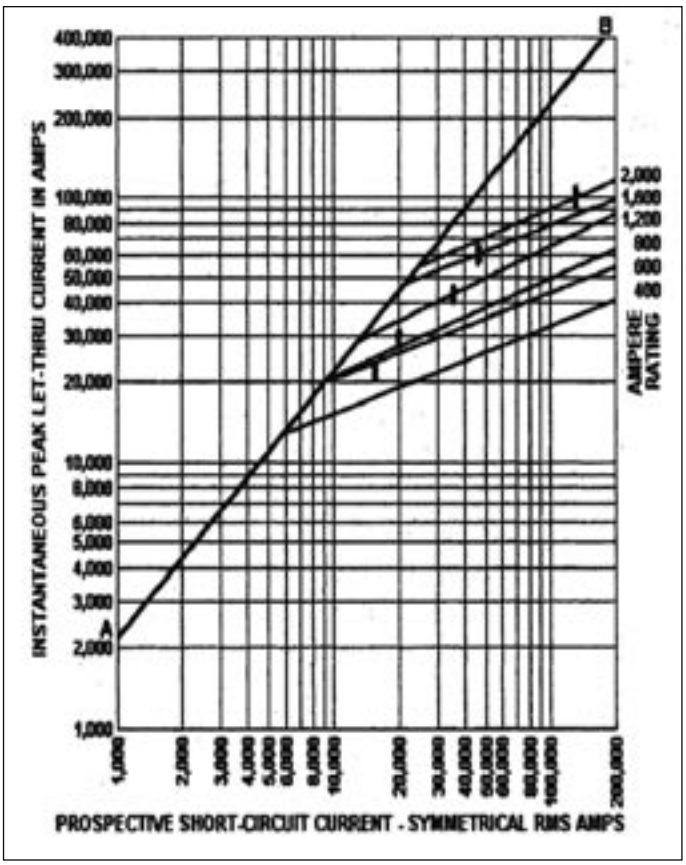

Fig. 17. Current-limiting fuse second-degree burn limit.

TABLE III
CLASS L FUSE—MINIMUM AVAILABLE BOLTED FAULT CURRENT TO MINIMIZE THE POSSIBILITY OF SECOND-DEGREE BURN AT 18 IN

System Description	Minimum Available Prosp. S. C. Current @ Fault Loc. To Minimize The Possibility Of 2nd Degree Burn @ 18"			
	Cl. L Fuse 2000A	Cl. L Fuse 1600A	Cl. L Fuse 1200A	Cl. L Fuse 800A
Bare Human Skin 1.2 cal/cm²	130 kA sym.	45 kA sym.	35 kA sym.	20 kA sym.
Class 1 FR Clothing 5 cal/cm²	80 kA sym.	30 kA sym.	25 kA sym.	15 kA sym.

determine the actual point at which the 800 A fuses limit the arc energy to below 1.2 cal/cm , somewhere between 22 600 and 44 100 A. Fig. 15 shows similar information for a 600-A Class RK1 fuse. In this case, since the fuse was smaller than the previous example, it should be current limiting at a lower bolted-fault current. The tests proved this to be true. For all values of available symmetrical bolted-fault current above 22 600 A rms, the incident energy was 0.15 cal/cm or less. At 5040 available bolted- fault amperes, the fuses were not in their current-limiting range, did not interrupt the fault within the allotted time, and the test operator interrupted the fault. Again, further testing could point out the actual point where the 600-A fuses begin to dramatically reduce the arc energy, somewhere between 5040–22 600 A.

V. FUSE ARC INCIDENT ENERGY PROTECTION LIMITS

Test data provide an indication of the boundary limits on fuse operation to minimize the risk of second-degree burn to human skin. Figs. 11–16 clearly indicate that, if a current-limiting fuse is not operating in the current-limiting region, the clearing time is significantly longer than 1/2 cycle, and there is increased incident energy produced from the three-phase arcing fault downstream of the fuse. When current-limiting fuses are applied, it is important for the user to understand the limits of protection from arc flash energy that apply to the specific fuse in use. Fig. 17 is a copy of the fuse let-through chart shown in Fig. 1 with the addition of vertical dashes on each fuse curve indicating where the second-degree burn limit (1.2 cal/cm) is reached for all test fuses except the 400-A Class RK1 fuse. To minimize the possibility of second-degree burn to bare skin of humans located no closer than 18 in from a three-phase arcing fault, the available symmetrical bolted-fault current intersection with the fuse line should be on the right side of the intersecting vertical dash.

Readers should be aware that data provided in Fig. 17 are based only upon measured incident energy under specified test conditions. Real arc exposures may be more or less severe than these laboratory-simulated arc exposures. The potentially hazardous effects of molten copper splatter, projectiles, pressure impulses, and toxic arc byproducts have not been considered in the test results or the analysis.

When using Fig. 17, be sure to determine the available symmetrical bolted-fault current at the potential location for the three-phase arcing fault. Any impedance between the fuse and the location of the fault must be included in determining the available bolted-fault current. For example, assume a 1200-A Class L fuse is installed in a fused low-voltage switchgear circuit breaker on the secondary side of a unit substation transformer. The available bolted-fault current on the line side of the circuit breaker is 65 000 rms symmetrical amperes. A long cable feeder is installed from the low-voltage switchgear feeder breaker to a remote motor control center. The available bolted-fault current on the motor control center main bus is calculated to be 45 000 rms symmetrical amperes. The design engineer wants to know if the risk of second-degree burn to the bare skin of personnel located 18 in away from the conductors in the main switch compartment of the motor control center has been minimized in the event of a three-phase arcing fault. Using 45 000 symmetrical rms amperes, the available bolted-fault current at the fault location, enter Fig. 17 and move up until the 1200-A Class L fuse line is intersected. The intersection is to the right of the second-degree burn limit mark, so the potential for a second-degree burn from this hypothetical exposure has been

minimized.

The test data for Class L fuses in Figs. 11-14 were interpolated to find the minimum available bolted-fault current that is required to minimize the possibility of second-degree burn to a person wearing Class 1 FR clothing, who is located no closer than 18 in from a three-phase arcing fault on a 600-V power system. Table III lists the minimum symmetrical bolted-fault currents to minimize the possibility of second-degree burn to a person with bare skin or to a person who is wearing Class 1 FR Clothing (arc thermal performance value (ATPV)-5 cal/cm).

This table indicates that, as fuse size increases, higher available short-circuit current is required to minimize the possibility of a second-degree burn (insuring that the fuse operates in the current-limiting region).

VI. USING LOW-VOLTAGE SWITCHGEAR FUSED BREAKERS AND FUSED SWITCHES FOR ARC FLASH PROTECTION

Low-voltage switchgear breakers and fused switches are often applied with listed current-limiting fuses. The current-limiting fuses increase the interrupting rating of the fuse-breaker assembly, and also have the side benefit of reducing the let-through energy in the event of a fault on the downstream side of the switch or breaker. (It is more difficult to predict results if "limiters" are utilized with switchgear breakers because the "limiters" do not typically have the let-through limits specified in the 248 series of fuse standards.) Using Table III, a power system designer can calculate the maximum length of a motor control center feeder (supplied from a fused low-voltage switchgear breaker or disconnect switch) to minimize the possibility for a second-degree burn to bare skin of personnel located 18 in away from an arcing fault on the main bus in the motor control center.

Table IV shows a tabulation of the maximum length of a motor control center (MCC) feeder to minimize the possibility of a second-degree burn to a person's bare skin located 18 in from an arcing fault on the 600-V MCC bus. The MCC feeder consists of two parallel 3/C-500-kcm cables. Maximum distances are shown for various substation transformer sizes. The available symmetrical bolted fault on the primary side of the substation transformer was assumed to be 500 MVA. Table V shows similar information for a person wearing a Class 1 FR clothing system as defined in [3].

VII. SYSTEM GROUNDING CONSIDERATIONS

In practice, the majority of faults experienced in industrial low-voltage systems are phase-to-ground faults. For solidly grounded wye systems, low-level phase-to-ground faults can easily burn down 480/277-V systems unless ground-fault protection is provided. This is the reason for NEC Section 230-95. While equipment ground-fault protection will not limit the magnitude of the arcing fault, it may limit the duration (if the relay operates instantaneously) and may prevent the fault from going phase-to-phase. Ground-fault protection will do nothing for a phase-to-phase, phase-to-neutral, or three-phase arcing fault. However, the use of current-limiting fuses for high-level phase-to-phase, phase-to-neutral, three-phase, and phase-to-ground arcing faults, and ground-fault protection for low level phase-to-ground faults, would seem to be an optimum combination of devices for minimizing arc flash hazards for solidly grounded systems.

Typically, for high-resistance grounded systems, the first phase-to-ground fault will be of such a low current value that no damage occurs, the phase overcurrent protective device does not open, and the plant continues to run. Ideally, the ground detectors, which are required by the NEC to be installed on the system, alert the maintenance crew to go out and fix the first fault, before a second fault occurs. While there are some issues with single-pole interrupting ratings of multipole molded-case circuit breakers, high-resistance grounded systems are an excellent choice for continuous process industrials where

TABLE IV
MAXIMUM 600-V MCC FEEDER LENGTH (2–3/C 500 KCM)
TO MINIMIZE SECOND-DEGREE BURN OF BARE SKIN
AT A DISTANCE OF 18 IN FROM ARC

Transf. KVA	Maximum Feeder Length, R., To Minimize 2nd-Degree Burn Of Bare Skin @ 18"			
	Cl. L Fuse 2000A	Cl. L Fuse 1600A	Cl. L Fuse 1200A	Cl. L Fuse 800A
1000	none	none	none	10
1500	none	none	none	275
2000	none	none	50	395
2500	none	25	130	460
3000	none	80	185	505
3750	none	130	230	550

TABLE V
MAXIMUM 600-V MCC FEEDER LENGTH (2–3/C 500 KCM)
TO MINIMIZE SECOND-DEGREE BURN OF A PERSON WEARING
CLASS 1 FR CLOTHING AT A DISTANCE OF 18 IN FROM ARC

Transf. KVA	Maximum Feeder Length, R., To Minimize 2nd-Degree Burn Of Bare Skin @ 18"			
	Cl. L Fuse 2000A	Cl. L Fuse 1600A	Cl. L Fuse 1200A	Cl. L Fuse 800A
1000	none	none	none	10
1500	none	none	none	275
2000	none	none	50	395
2500	none	25	130	460
3000	none	80	185	505
3750	none	130	230	550

qualified maintenance personnel are available on a 24-hour basis. The high-resistance grounding scheme will do nothing for phase-to-phase or three-phase arcing faults, but the combined use of high-resistance grounding for ground faults and current-limiting fuses for phase-to-phase and three-phase arcing faults is an effective way to minimize arc flash hazards.

While many new industrial installations are being installed with high-resistance grounded systems, it was common practice many years ago to install ungrounded systems. Because there are so many ungrounded plants still in existence, and because these plants are still undergoing expansion, it is essential that the engineer also understand the effects of ungrounded systems on arc flash hazards. Typically, for ungrounded systems, the first phase-to-ground fault will also be of such a low current value that no damage occurs, the phase overcurrent protective device does not open, and the plant continues to run. While ground detectors are not required by the NEC, they are really a necessity in order to alert the maintenance crew of the first fault to ground, so that the fault can be found and removed before a second ground fault occurs (The second fault to ground from another phase is actually a phase-to-phase fault and, therefore, can be of a very high magnitude). There are similar issues with the single-pole interrupting rating of multipole molded-case circuit breakers used on these systems and issues with high transient voltages on the other phases during arcing conditions. As with high-resistance grounding schemes, ungrounded systems will not affect phase-to-phase or three-phase arcing faults, but the combination of an ungrounded system for ground faults and current-limiting fuses for phase-to-phase and three-phase arcing faults minimizes arc flash hazards.

Another grounding scheme that was quite popular, and is still being used, is the corner-grounded delta system. One corner of the delta is intentionally grounded, and has no overcurrent protection in that phase. (A fuse can be used in the grounded phase if it is providing motor running (overload) protection, or a three-pole circuit breaker can be used if all three poles open simultaneously.) The advantage of such a system is that 1/3 of potential ground faults are eliminated because one phase is already intentionally grounded. Faults from either of the other two energized phases are at full line-line voltage and require overcurrent devices capable of handling the phase–phase voltage across only one pole. While the corner-grounded delta system offers help by eliminating 1/3 of the phase-to-ground faults, and no help for energized phase-to-phase or energized phase-to-ground faults, the addition of current-limiting fuses for phase-to-phase and three-phase arcing faults also minimizes arc flash hazards associated with these systems.

VIII. CONCLUSIONS

A test program has been conducted to examine the let-through characteristics of current limiting fuses when located upstream of a three-phase arcing fault. The effects of arc impedance and fuse current limitation in reducing available bolted-fault current have been quantified. Incident energy 18 in from a three-phase arcing fault in a 20-in cubic box downstream of a current-limiting fuse has been measured. The benefit provided by correctly applied current-limiting fuses in minimizing second-degree burn of human skin has been verified.

When low-voltage switchgear utilizes fused switches or circuit breakers with properly sized Class L fuses, and the motor control center feeder length is limited as indicated in Table IV, then the probability of an electrical worker receiving flash burns on bare skin from arcing faults at a distance of 18 in from the motor control center is minimized. From a design viewpoint, such an electrical system would be optimized by reducing the potential arc flash hazard to a practical minimum without requiring the purchase of arc-resistant motor control equipment.

Results of the test program indicate that correctly applied current-limiting fuses are an effective measure to reduce potential exposure to thermal hazards associated with arc flash. If proper application of current-limiting fuses is coupled with the use of high-resistance grounded systems, ungrounded systems, corner-grounded delta systems, or solidly grounded wye systems with ground-fault protection, the potential for arc flash injuries and equipment downtime from arcing faults on 600-V electric power systems can be minimized.

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Significance Of Scenarios In Arc Flash Studies

By Brian Radibratovic, PhD, Director of Power Engineering, EDSA

Introduction

Most of the arc flash studies done today use commercially available software. Software calculates arcing energy using the algorithm presented in IEEE-1584. Software performs short circuit calculation to calculate available bolted fault current; arcing current is derived from bolted fault current; arcing current is then used to calculate fault clearing time; finally the arcing energy is calculated using IEEE-1584 formulae.

The importance of evaluating multiple scenarios is widely recognized within the engineering community. As the problem is nonlinear, it is not necessarily true that high bolted faults result in the highest arcing energies. It happens often that lower fault current causes higher arcing energy. In search of the highest possible arcing energy, engineers evaluate multiple scenarios and perform multiple arc flash calculations.

The goal of this paper is to present good practices in evaluations of multiple scenarios, and to demonstrate some peculiarities engineers should be aware of while searching for those worst-case results. An alternative approach, the "Real-Time Arc Flash", is presented. In specific environments, it can significantly simplify the search for the worst-case scenario.

Arcing energy dependence on fault current and fault clearing time

Arcing energy essentially depends on arcing current and fault clearing time. An increase in arcing current will cause higher energy, provided that fault clearing time is constant. An example of that is shown Figure 1.

Distribution panel DPA, Figure 1, is protected by a fixed magnetic breaker. Arcing current on DPA is in the order of 7.7 kA, which is well within the instantaneous "setting" of this breaker. An increase in available arcing current is bound to cause higher arcing energy as the fault clearing time will stay constant.

Often, arcing current falls in the I2t region of solid state protective devices. Such a case is shown in Figure 2. Here, if arcing current is reduced, fault clearing time will increase which will cause an increase in arcing energy. For the case shown in Figure 2, arcing current is around 16 kA and the corresponding arcing energy is 32.3 cal/cm2. If the current is reduced to 15.5 kA, the energy will become 34.5 cal/cm2.

The above examples illus-

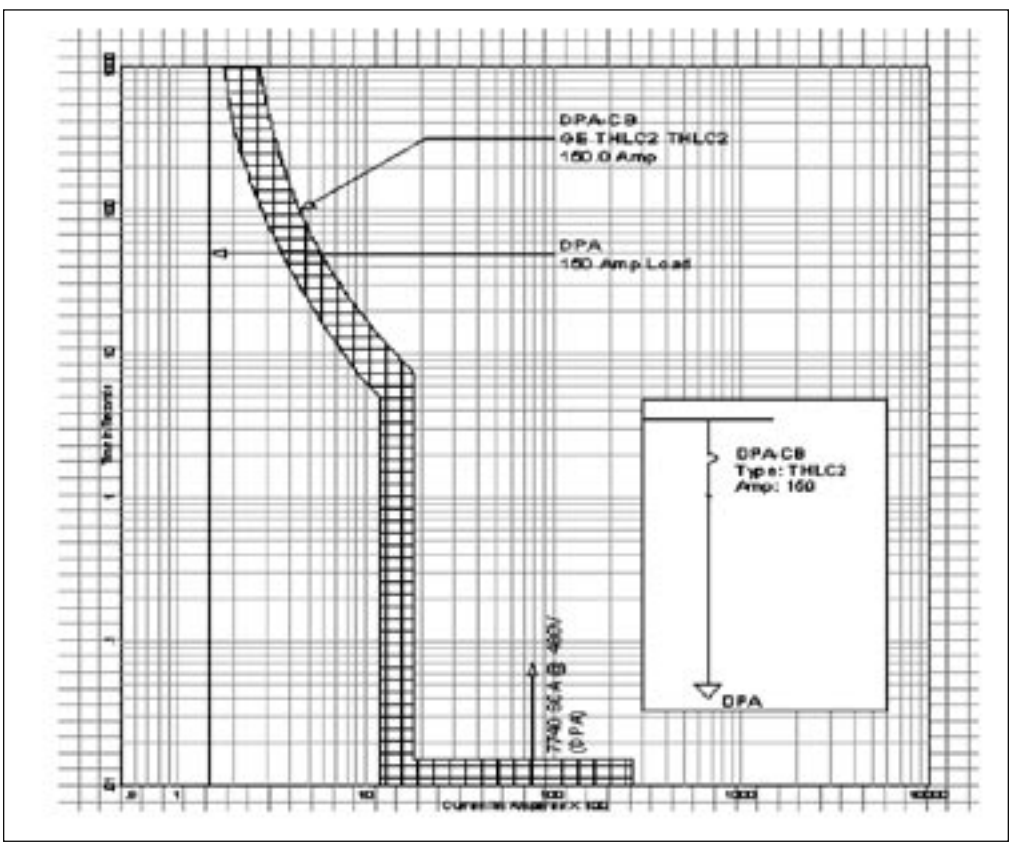

Figure 1. Case where increase in arcing current will cause higher arcing energy.

trate the necessity to evaluate several network configurations. Different configurations (scenarios) will produce different short circuit levels, which translate to different arcing currents, fault clearing times, and finally, different arcing energies and arc flash boundaries.

HIGH VS. LOW SHORT-CIRCUIT CURRENTS

SHORT-CIRCUIT LEVEL IN THE NETWORK DEPENDS PRIMARILY ON:

- Network configuration (tie-breaker position, generators are running, etc.)
- Available fault from the utility
- State of the large motors in the network (running or not)

Sometimes (but not very often) an electric power utility will provide information about minimum and maximum short circuit current. If this information is available, it is wise to analyze at least two scenarios:

- Maximum utility contribution + all motors are running
- Minimum utility contribution + none of the motors are running

The above scenarios are bound to find the minimum and maximum short circuit results throughout the network.

If the facility has standby generators, it is expected that the minimum short circuit will be obtained when systems are fed from generators. Therefore, one may want to evaluate the following scenarios:

- Maximum utility contribution + all motors are running + generators are on or off (depending on the way the system is run)
- Utility off + generators are running + none of the motors are running

However, things get more complex if there are several points of coupling with the utility and the coupling transformers are of different sizes. One such system is depicted in Figure 3. The system is a simplification of many networks the author has encountered in the past.

The system in Figure 3 has 500 kVA and 2000 kVA transformers feeding the separate switchgears. There is also an abundance of local generation. Due to the high impedance of 500 kVA transformer, fault level at the BUS-1 is significantly lower than the fault level at the BUS-2 (e.g. 10 kA vs. 35 kA). It can happen that if the system is fed from generators, the fault level at both buses is between these two extremes (e.g. 20 kA). Therefore, one can draw the following conclusions:

- BUS-1 has maximum fault level when fed from generators
- BUS-1 has minimum fault level when fed from utility
- BUS-2 has maximum fault level when fed from utility
- BUS-2 has minimum fault level when fed from generators

Consequently, one needs to evaluate at least four scenarios to find min/max fault levels. It should be noted that in the previous example we did not discuss motors (running or not) or variation of utility short-circuit contribution.

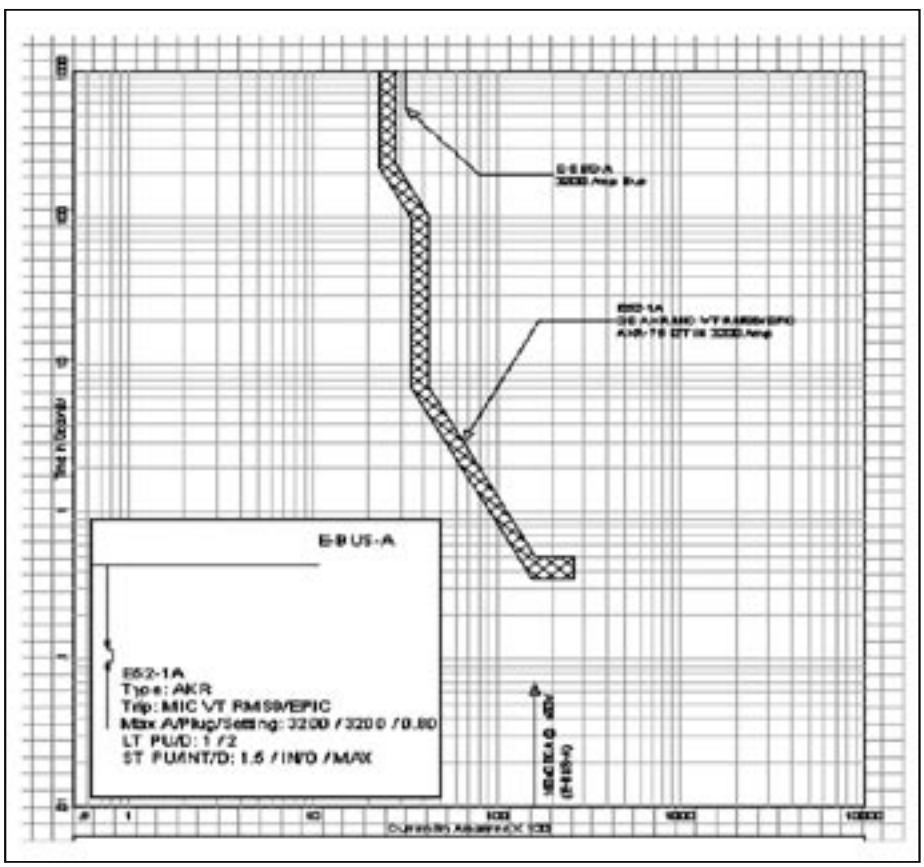

Figure 2. Case where decrease in arcing current will cause higher arcing energy.

ARE MAXIMUM AND MINIMUM SHORT CIRCUITS ENOUGH?

So far, we have established a connection between different fault levels and arcing energy. We have seen that decreasing the fault level can increase arcing energy; we have also seen that increasing the fault level can increase energy of the arc. We have also discussed methods of how to find the maximum and minimum fault level in the network. The next logical question is if maximum and minimum fault cases are bound to reveal the worst-case arc flash. The answer is, unfortunately, no.

Let's analyze BUS-2 from Figure 3. And let's assume that its protection is similar to the one shown in Figure 2. It should be expected that the worst-case arc flash scenario will correspond to the minimum fault level at BUS-2. Minimum fault level at BUS-2 will be obtained when the system is fed from generators with no motors running. However, there is a large motor contribution to the fault from Chiller-1. This fault current will

not flow through breaker CB-BUS2-1 responsible for clearing the fault; hence, it will not influence the fault clearing time. Therefore, the maximum arcing energy at BUS-2 will be obtained when:

• System is fed from a generator – minimum fault current to the protective device causes maximum fault clearing time

• Chiller-1 is running – increased fault current at the bus (not branch CB-BUS2-

1) will not influence fault clearing time, but will help additionally increase the energy.

This example illustrates that there are special cases where it is not enough to find min/max fault regimes. Additional analysis is needed if one is to find the worst-case scenario.

HOW TEDIOUS IS ALL OF THIS?

Previous sections illustrated the need to evaluate multiple scenarios even in the case of relatively simple systems. As systems become more complex, the number of necessary scenarios naturally increases. Some of the available power system analysis software is well equipped for creating multiple scenarios and providing the worst-case results in one arc flash run. An example of such analysis is shown in Table 1; Paladin DesignBase software from EDSA is used for this demonstration. The Paladin DesignBase family consists of more than 40 integrated modules for specialized design and analysis functions – e.g. arc flash, power flow, short circuit, protective device coordination, etc. – and analysis results from any program can be easily incorporated in the master design model.

Therefore, proper arc flash analysis requires a knowledgeable engineer, capable software and a fair amount of time invested in the search for the worst-case scenario.

REAL-TIME ARC FLASH ANALYSIS

Many modern mission critical facilities have state-of-the-art data acquisition systems. These systems gather a plethora of information about system configuration: position of switching equipment, state of generators, state of motors, etc. At any given point in time, all of the conditions discussed in the previous sections are known. If all of this data is transferred to the facility model, arc flash calculations would give the exact results at a given time. Moreover, if the model is to follow the system in real-time (every change in the system is immediately reflected in the model) multiple arc flash calculations would explore all the system configurations and therefore find the worst-case arc flash results.

Paladin Live System does exactly the above. The model-based interaction between Paladin Live and the original DesignBase model ensures that "as-is" power system performance is within the parameters of the "as-designed" model. This enables facility operators to manage the electrical infrastructure as a "power network," interfacing to any data acqui-

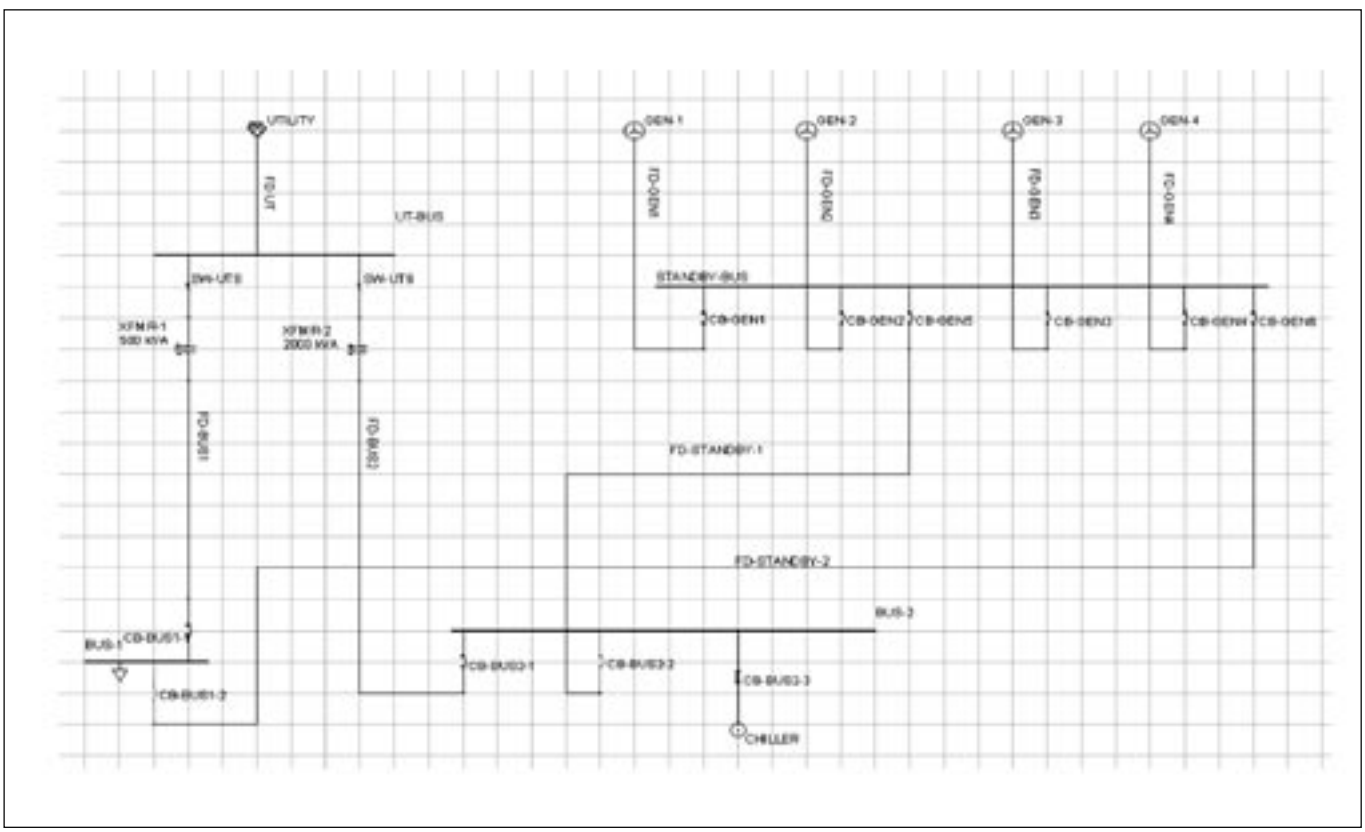

Figure 3. Example System with Two Utility Connections.

sition system or building management system to ensure the optimal performance of all power assets.

By enabling real-time model-based diagnostics of power systems infrastructure – incorporating the arc flash, power flow, short circuit, protective device coordination, etc. calculations from the original design model -- Power Analytics enables a facility operator to glean unprecedented visibility into operational detail and previously unpredictable events.

Having real-time arc flash, the facility manager does not need to worry about the off-line arc flash study he received. Did the consultant find the worst case results? Did he assume some impossible scenarios and hence reach overly conservative results? These questions become obsolete. The system will go through all the relevant configurations; therefore, all relevant scenarios will be explored.

Moreover, real-time arc flash analysis presents users with current arc flash results. A user knows the exact arcing energy for the given system configuration, and can use that knowledge to perform work under energized conditions while the arc flash hazard is less severe.

The user may be hesitant to use the current arc flash results. A typical question is: What if the system changes between now and when an electrician actually opens that panel? Sometimes this is a legitimate fear. To that end, real-time arc flash analysis stores all the results obtained over time and the user can decide to use:

- Worst-case results for the last week, month or perhaps a year
- Worst-case results for the first/second/third shift

Perhaps the most important aspect of real-time arc flash analysis is the opportunity for the user to understand how different system configurations impact arc flash hazard. For example, the user can realize that when the system is fed from standby generation, the energy at a given panel is always above 20 cal/cm2 while if the system is fed from the utility, the energy is well below 20 cal/cm2. Hence, he can decide to send the electrician to work on that panel when the system is not on generators.

CONCLUSION

This article demonstrates the necessity of evaluating different scenarios while performing arc flash analysis. The most important aspects of engineering reasoning behind the scenario selection are depicted. An alternative method, real-time arc flash, which automates the process of scenario selection, is presented.

Bus Name	Worst Scenario	Bus kV	Bolted Fault (kA)	Arcing Current (kA)	Fault Duration (sec)	Arc Flash Boundary (inch)	Working Distance (inch)	Energy (cal/cm^2)	PPE Class
B-BSWBD-A	2	0.480	34.57	15.455	2.768	462.6	24.0	93.3	Danger
B-BSWBD-B	2	0.480	34.81	15.545	2.733	460.6	24.0	92.6	Danger
B-BWP-1A-1	4	0.400	36.95	16.741	0.060	34.5	17.9	3.5	1
B-BWP-1A-10	4	0.400	30.21	14.225	0.062	31.0	17.9	2.9	1
B-BWP-1B-1	5	0.400	33.62	15.510	0.060	32.8	17.9	3.2	1
B-BWP-1B-10	5	0.400	38.95	17.471	0.060	35.5	17.9	3.7	1
B-MDP-8B	5	0.480	31.54	17.494	0.060	35.5	17.9	3.7	1
B-MDP-9A	4	0.480	32.72	18.053	0.060	36.3	17.9	3.8	1
B-MDP-9B	5	0.480	35.05	19.146	0.060	37.7	17.9	4.0	2
B-PDU-1A	4	0.208	13.44	5.352	0.200	33.9	17.9	3.4	1
B-PDU-1B	5	0.208	12.48	5.082	0.200	32.8	17.9	3.2	1
B-PDU-2A	4	0.208	13.46	5.360	0.200	33.9	17.9	3.4	1
B-PDU-2B	5	0.208	12.42	5.066	0.200	32.7	17.9	3.2	1
B-PDU-3A	5	0.208	13.37	5.334	0.200	33.8	17.9	3.4	1
B-PDU-3B	5	0.208	12.41	5.061	0.200	32.7	17.9	3.2	1
B-PDU4A-1	2	0.208	13.17	4.707	1.012	83.7	17.9	15.0	3
B-PDU4B-1	2	0.208	12.76	4.606	1.063	85.0	17.9	15.4	3

Table 1. Worst Case Arc flash Results Obtained Using DesignBase Software.

Buyer's Guide

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One-Touch PDC and Design Tools Now Available in EasyPower 8.0!

What used to take hours or even weeks can now be accomplished in seconds. Finally, truly automated design and device coordination is here. With **EasyPower**'s one-touch automation, you don't need to make manual calculations or memorize electrical codes. For the first time, even those without design experience can complete comprehensive design and analysis tasks.

SmartDesign™ | Automated Design for Low-Voltage Systems

EasyPower SmartDesign™ completely automates equipment sizing in the design process, saving countless hours of manually rerunning calculations to verify code compliance. It also generates comprehensive reports to alert you to possible problem areas, giving valuable insight. There's no need to reinvent the wheel with SmartDesign™; just set up your design sheets ONCE, and SmartDesign™ does all the rest for you.

SmartPDC™ | Protective Device Coordination Made Easy

EasyPower SmartPDC™ fully automates the tedious, labor-intensive work of setting protective devices — just highlight an area to coordinate, and one click completes the task for you. Intelligent reporting automatically provides a list of devices and setting options, with a detailed description explaining each setting. It's like having the industry's brightest engineers right inside your PC.

About ESA, Developers of EasyPower

Since 1984, **ESA** has redefined the way companies manage, design, and analyze electrical power distribution. Our innovative technologies make power system design and management simpler, smarter, and safer than ever. We invite you to visit www.EasyPower.com for a complete overview of all the powerful options available within **EasyPower 8.0**!

Power made easy

intelligent | intuitive | instantaneous power system software

WHY EASYPOWER?

- Easiest to use
- Fastest algorithms and results
- Intuitive graphical user interface
- Shortest learning curve
- Most accurate, lowering liability/risk
- Follows Windows® standards
- Complete integration of all functions

CLICK ONCE TO...

- Size equipment per National Electric Code
- View/modify integrated one-line data
- Perform complex arc flash calculations
- Verify duty ratings and compliance
- Analyze switching conditions instantly
- Study countless operating scenarios
- Generate detailed reports
- Access critical documentation
- Print compliant work permits and labels

"EasyPower 8.0 really knocked my socks off. I don't know of any other program that comes close to its speed and automation — that auto-coordinates and eliminates all the guesswork.

Typically, setting devices takes up to 15 minutes — sometimes longer — per circuit, depending on the complexity. But with EasyPower SmartPDC, it literally takes only 5 to 15 seconds. Just amazing!

Tie this all in with new automated design features, the ability to conduct studies, and having a fully integrated database - and watch productivity skyrocket."

— *Jim Phillips*, P.E. T2G Technical Training Group

TRY BEFORE YOU BUY

Download a Free Demo!

ONLINE PRESENTATION

Witness the speed and automation of EasyPower and ask engineers specific questions during a live online product presentation.

Sign up today. It's free!

Tap into the power of EasyPower! Download a FREE demo or sign up for a free live, online presentation:
www.EasyPower.com | 503-655-5059 x35